



APPLYING THE PASSIVHAUS STANDARD TO TERRACED HOUSING IN JAKARTA – ANALYSIS FOR A HOT AND HUMID, TROPICAL CLIMATE

Thesis submitted in accordance with the requirements of the University of Liverpool

for the degree of Doctor of Philosophy (PhD)

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DECLARATION

I certify that this work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted parallel in application for any degree or other award. This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references. The views expressed are my own.

A handwritten signature in black ink, appearing to read 'Roy Candra Sigalingging', is centered on the page. The signature is stylized with a large initial 'R' and a long horizontal stroke at the end.

Signed: Roy Candra Sigalingging

Date: 2 January 2020

ABSTRACT

In a hot and humid tropical region, the air's moisture level is high. The external humidity levels are very high in hot and humid tropical regions, thus using natural ventilation to reduce indoor humidity levels due to occupant activities is not effective. The use of air conditioning to cool rooms and reduce relative humidity in dwellings is an energy-intensive approach and it is also energy-inefficient as the conditioned air is lost through the building envelope via ventilation and air infiltration. The German Passivhaus standard's approach in tropical housing might be effective in preserving stable interior temperatures, however special attention is needed regarding the removal of excess moisture.

The aim of this research was to investigate the thermal comfort and energy-saving implications of applying Passivhaus principles to existing urban row houses in Jakarta, Indonesia. The goal was to achieve minimum carbon emissions whilst maintaining a comfortable environment. This thesis investigates the feasibility of the Passivhaus standard in the context of Indonesia by comparing the performance of the two buildings models in terms of energy savings, and thermal comfort, using dynamic thermal simulations. The building model was created from the case study information and was validated using real-time monitored data. The thesis will investigate the effects on indoor temperature and humidity on comfort and energy use by gradually improving insulation levels and airtightness to the Passivhaus standard, to find the optimum setting for reducing cooling and dehumidification energy in air-conditioning. This study examined the effects of air conditioning (AC) and/or dehumidifiers on thermal comfort and cooling load through numerical simulation using the PHPP, DesignBuilder and IES VE software.

The findings highlighted the potential energy saving and at the same time bring comfort to the rooms by applying the Passivhaus standard. Assessments of the results enabled the optimum insulation and air-tightness settings to be determined for minimizing cooling and dehumidification energy use in the air-conditioning system. The research highlighted the potential energy saving from removing the floor insulation of the Passivhaus standard. The research concludes with several key features that could possibly be applicable in the context of hot and humid climate, and which highlight the possibility of a promising transition towards low energy buildings that are ready to face the region's future challenges.

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Chapter One

1 INTRODUCTION

1.1 Overview

Global warming has become an important issue this century. The average global temperature from 1880 to 2012 has increased by 0.85 °C, and it is likely that by the end of this century the global mean temperature will continue to rise above the pre-industrial level (United Nations, 2019). Indonesia is in the top 20 of countries that emitted the most carbon dioxide in 2015 (Union of Concerned Scientists, 2018). Indonesia's energy consumption has increased in recent years, from 0.40 metric tons per capita in 1975 to 1.89 metric tons per capita in 2010 (Shahbaz et al., 2013). The National Planning Agency (Bappenas) forecasts that, exclusive of any involvements, Indonesia's GHG emissions will climb from slightly below 1.5 GT CO₂e in 2010 to 1.8 GT CO₂e by 2020 and will touch 2.9 GT CO₂e by 2030 (Maulidia et al., 2019). The household sector is contributing around 31% of the total energy consumption in 2017 (Figure 1-1) and this proportion increase gradually since 2007 (Figure 1-2) (ESDM-RI, 2018). Active measures from the government and private sector in housing sector are needed as a means of reducing national carbon emissions.

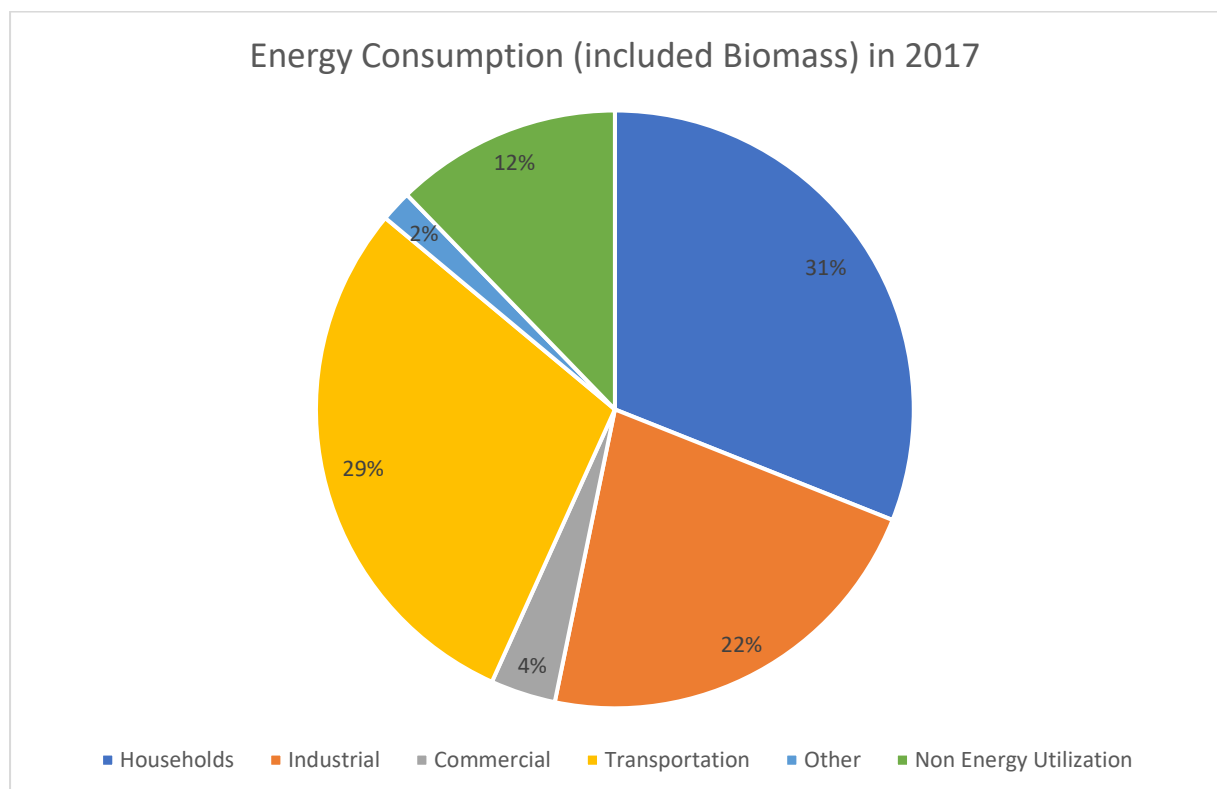


Figure 1-1 Energy consumption (include biomass) in 2017.

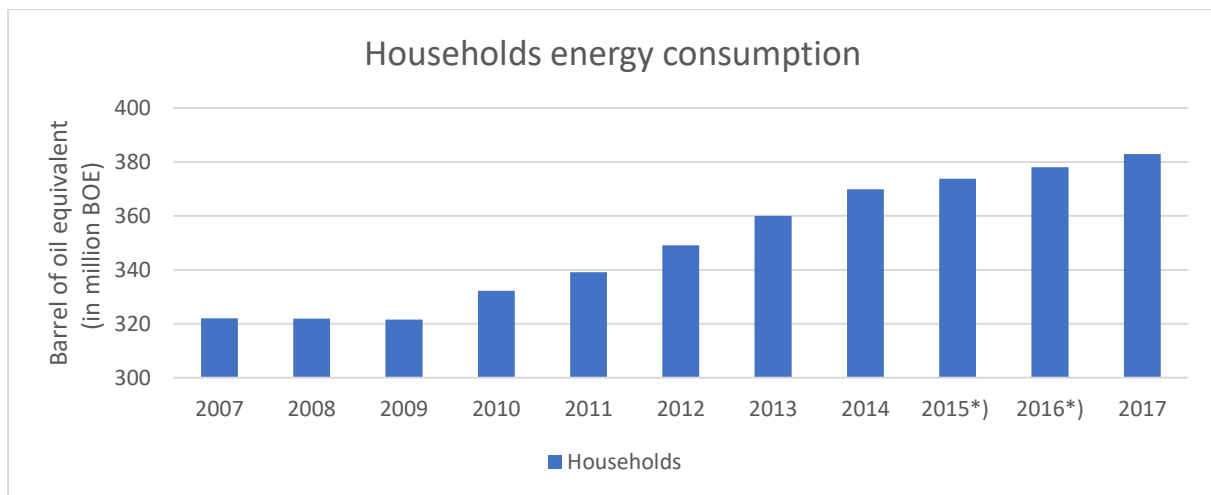


Figure 1-2 Household energy consumption (include biomass) in 2017.

Population growth and a preference for low-density housing by Indonesians have contributed greatly to the uncontrolled urban sprawl around the peripheries of Indonesia's major cities (Rahadi et al., 2015). The population growth rate in Indonesia is 1.03 per cent, 17.7 births/1000 with 6.3 deaths/1000 and 44 per cent of total population is living in urban areas in 2012 (Shahbaz et al., 2013). The capital city Jakarta has a high demand for dwellings to support urbanization. The housing developments are growing mostly into the satellite city by developing new towns. These new towns mainly consist of low density, single-family houses, and exclusive residential areas for middle- and upper-income groups (Firman, 2004).

Traditionally, in the tropical region, passive cooling strategies were established and applied in vernacular houses to overcome prevailing winds and orientation to the sun. The traditional houses were commonly using one layer of timber wall that is not airtight. Unfortunately, new building designs' development mostly do not reflect local climatic conditions and the need for energy conservation as they are mostly developed to rapidly fulfil the high housing demands (Al-Tamimi and Syed Fadzil, 2011; Tantasavasdi et al., 2001). The avoidance or inappropriate applications in contemporary house designs is an important issue that needs addressing. These have resulted in new buildings there is overall not airtight and have poor thermal performance of and the need for mechanical ventilation and air conditioning that result in inefficient use of air-conditioning and lead to high rate of energy consumption (M. Al-Tamimi et al., 2011). The monthly average use of electricity consumption households is between 300-400kWh (Santy et al., 2016). Based on world bank data, electricity consumption/population per capita in 2017 was 890kWh and this number was increase every year, where in 2007 the

number was in 540kWh (iea, 2019). The government through “*Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi*” (EBTKE) states that the housing sector need to lower the energy consumption by developing efficiency on air-conditioning unit (EBTKE, 2019).

In hot and humid climates, the application of simple cooling measures can be effective in reducing the cooling load of buildings. Reductions of up to 43% in cooling load can be achieved using a combination of well-established technologies such as glazing, shading, insulation, and natural ventilation (Omer, 2008). Properly designed ventilation in a house will provide enough fresh air to keep the occupants healthy, remove odors and dilute indoor pollutants. But with high outdoor relative humidity, ventilation alone is not able to reduce internal relative humidity. Approximately 30–50% of the energy used for cooling is also lost through ventilation and air infiltration (Omer, 2008). It is crucial to find cooling strategies that, whenever possible, are energy efficient for houses experiencing hot and humid climatic conditions. Any design approach to the building that are able to bring comfort to the rooms and are energy efficient are very important. A building design methodology that is adaptive with the climate is significant as it provides thermal comfort and energy savings for occupants, therefore sustaining people’s wellbeing and the planet’s precious resources.

One of the fastest-growing energy-efficient standards is the Passivhaus standard. More than 50,000 buildings have been built around the world following this standard, although most of them have been constructed in Europe (Lewis, 2014). The German Passivhaus standard. “*A Passivhaus is a building in which thermal comfort can be guaranteed solely by heating or cooling of the supply air which is required for sufficient indoor air quality without using additional recirculated air*” (McLeod et al., 2013). The Passivhaus standard ensures indoor air quality, durability, and thermal comfort in the building. To achieve certification as a Passivhaus a project must demonstrate compliance with the Passivhaus standard that will be described in Chapter 3. The Passivhaus criteria regulate the heating and cooling demand, the airtightness, and renewable energy generation. For a building that require heating, the annual heating demand requirement must be less than or equal to 15 kWh/m²/year and primary energy use must not exceed 120 kWh/m²/year (Brew, 2011), whereas the cooling demand will be based on the dehumidification contribution (Passive House Institute, 2016). With extreme air tightness and high thermal resistance R-values in Passivhaus construction, the application of the Passivhaus standard must properly consider moisture balances and the attendant latent

loads on the building in a hot humid climate. A failure to do so can lead to discomfort or moisture-related problems, such as mould growth (Walker and Sherman, 2007).

The objective of this study was to determine energy-saving modifications through the application of the German Passivhaus standard to Jakarta urban houses. The target houses chosen for analysis were row (terrace) houses, which form the majority of the existing urban housing stock (Badan Pusat Statistik, 2011). This study analyzed the effects of air conditioning (AC) and dehumidifiers on thermal comfort and cooling load through numerical simulation using PHPP program, the DesignBuilder, and IES VE. This research presents the application of the German Passivhaus standard to reduce domestic energy use whilst creating thermal comfort in housing built in the tropical climate of Indonesia. Analysis was done by investigating the typical housing characteristic, building performance (in this case are air temperature and relative humidity), and energy consumption. The research then continued by applying the German Passivhaus standard to Indonesian dwellings building model in order to study the building performance and energy consumption, especially for cooling energy needs. With the Passivhaus standard on the building model built, the analysis also made for the performance of the building with the impact of climate change.

1.2 Research Aims and Objectives

The aim of this study is to examine the likely benefits, in terms of energy savings and thermal comfort, if the Passivhaus energy-efficient model was to be applied into terrace housing in Indonesia with its hot and humid climate. The study, therefore, targeted a number of objectives, as listed below:

1. To develop low energy tropical dwellings by improving insulation levels and airtightness to meet the Passivhaus standard for Jakarta urban houses.
2. To consider the effects on air temperature, relative humidity, thermal comfort and energy use by incrementally improving insulation levels and airtightness to meet the Passivhaus standard.
3. To analyze the effects of air conditioning (AC) and dehumidifiers on thermal comfort and cooling load through software simulation.
4. To explore how Passivhaus dwellings in Indonesia could withstand the impact of climate change.

5. To detect the possible challenges that could be associated with the implementation of the Passivhaus standard in Jakarta - Indonesia.

1.3 Research Questions

The research presented in this thesis addresses a number of questions that are associated with above hypothesis, aims and objectives. This study targets to answer the following main research question:

1. What is the importance of introducing the Passivhaus standard as an energy-efficient model for Jakarta?
2. How well does the Passivhaus building model perform in comparison to the standard building model within a tropical climate?
3. What key features of the Passivhaus building can be applied to local buildings to improve their performance and sustainability?
4. If the Passivhaus building was expected to perform better than the standard building at the present time, how well is it expected to perform under the impact of climate change?
5. Is it possible to create comfort in the Passivhaus building without an air-conditioning system?
6. What are the barriers that may be associated with the implementation of the Passivhaus concept in Jakarta?

1.4 General Methodology

This thesis explored the Passivhaus standard design approach and requirements as well as demonstrate its application to new projects in the hot humid climate context. Successful designs carefully manage the requirements and recommendations, to achieve a comfortable indoor environment. The following levels of exploration were undertaken to thoroughly address the performance of the Passivhaus building, as follows (Figure 1-3):

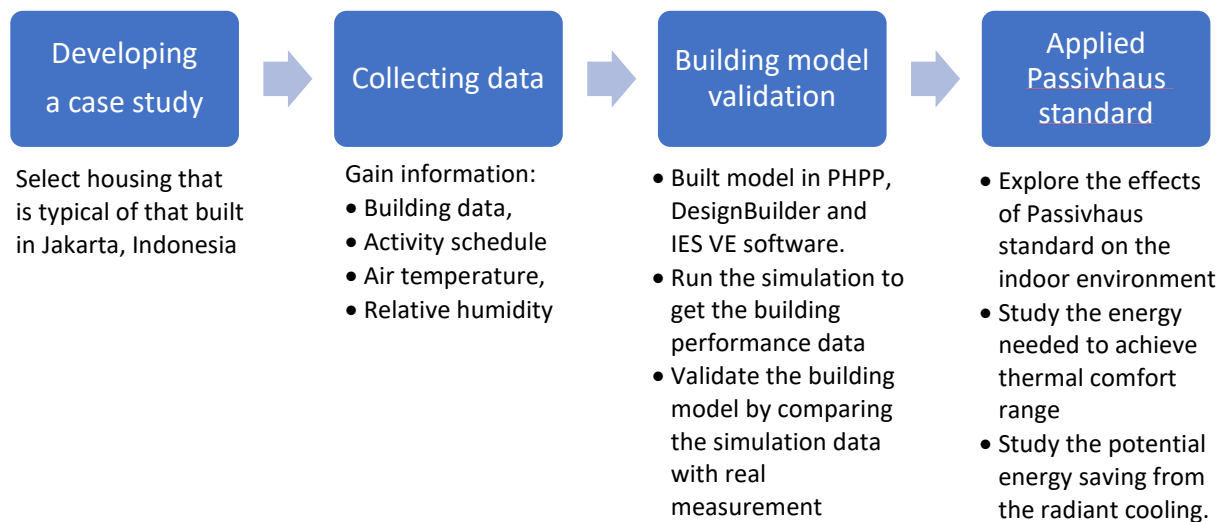


Figure 1-3 General methodology

The performance of a dwelling in Jakarta built to the Passivhaus standard in the hot humid climate was examined in this research, with the focus on the energy used to achieve thermal comfort and the needs for dehumidification. The building model was made by translate the case study information into building model in PHPP, DesignBuilder and IES VE software. The building model was validated using measured data on the case study dwelling. This validated model was used to explore the effects on the indoor environment when applying the Passivhaus standard to the row house and to study the energy needed to achieve thermal comfort. The main goal of this study was to test the potential application of the Passivhaus standard to Jakarta houses with tropical conditions. This research presents the results from an analysis of thermal comfort and energy efficiency after implementing the Passivhaus standard to a residential building in the hot and humid climate of Indonesia.

The analysis was also continuing by studying the potential energy saving from the removing the floor insulation from the Passivhaus model and study the building performance in the future climate.

1.5 Thesis Outline

The structure of this thesis has been broken down into three main parts; the first part is the contextual review, followed by descriptive review, and are summarized by analytical review. The chapters are constructed to include an opening overview, which presents an introductory statement and introduces the outline of the chapter. At the end of each chapter, a summary

section is included which recaps the main ideas of the chapter and introduces the subsequent chapter.

Part One: this part comprises *Chapters Two* and *Three*, which contain the necessary background literature that sets out the context on which this study rests. Chapter two is describe the important of energy efficiency in the building environment that not only regulates energy use, but also mitigates GHG emissions and assurances better indoor thermal comfort. This chapter is exploring the connection between insulation, thermal comfort, air-conditioning, and building energy demand. This chapter will be describing the background on applying the Passivhaus standard in hot and humid climate.

Chapter three will shed light on the Passivhaus standard. This chapter expands to detail the Passivhaus approach, its evolution and implementation in varying contexts. The chapter includes the recent Passivhaus criteria and the main concepts that are to be applied. It also presents a number of studies and findings that evaluated the performance of Passivhaus buildings mainly within Europe. Finally, a number of Passivhaus case studies in hot climates are highlighted at the end this chapter.

Part Two: this part comprises *Chapters Four, Chapter Five* and *Chapter Six*, which contain a detailed description of the project and the evaluation methods adopted. Chapter Four is describing the general information about the climate in Indonesia, the temperature variations between dry and rainy seasons. This chapter than explaining the background on choosing the case study house, in relation with the housing development in Jakarta Metropolitan Region. With the selected case study, the monitoring process was done in two selected periods, one in the rainy season and the other one in the dry season. Monitoring of these parameters was undertaken by using loggers that were placed in the two main activity in the house that is the master bedroom and the living room + kitchen area. There is one logger used to monitor outdoor area that placed right outside the main door.

Chapter Five is explaining about the selection of the Building Performance Simulation (BPS) tool, the background on choosing two BPS tools. The first was DesignBuilder, which was the most commonly used BPS tool amongst researchers in the University of Liverpool. The second software is the Integrated Environmental Solutions – Virtual Environment (IES-VE) software, that provided the student version of the software. Since the research was analyzing the

Passivhaus standard application in typical dwelling built with hot and humid climate, The Passive House Planning Package (PHPP) software was then used in this research to analyze the Passivhaus application into the building model.

In chapters six, the selected BPS tools than used to create the case study building model. In this chapter, the description of DesignBuilder and IES VE building model validation process that using measured data was explained and described. The simulation results from case study building model was analyze and compared with measured data. The validation process is using evaluating indicator that based on the specifications of the Guideline ASHRAE 14-2002 (ASHRAE, 2002).

Part Three: this part comprises *Chapters Seven, Chapter Eight* and *Chapter Nine*, containing the findings analysis followed by the discussion chapter. It starts with the Passivhaus standard application into the validated model that is described in Chapter Seven. This part explored the Passivhaus approach in a tropical climate building. PHPP, DesignBuilder and IES VE 2018 software were then used to study the output from the application of the Passivhaus standard on the validated building model house. The initial analysis in PHPP software had indicating that wall insulation was important in the tropical country, but additional insulation thickness in the wall does not improve the building performance. And the analysis indicated that it is important to have roof insulation on the Passivhaus building in tropical climate to reduce the cooling energy significantly. The chapter is also highlighted that the housing built in a hot and humid climate does not require any floor insulation.

The chapter explain that the modeled house needed a means of active dehumidification to achieve optimal control over the comfort zone. Cooling with dehumidification were key strategies in reducing relative humidity in the modeled house. The finding has also suggested that the Passivhaus application was significantly reduce the cooling energy. By applying Passivhaus standard, the cooling energy yearly can be reduced by half compare to original building element and at the same time bring comfort to the occupant.

Introducing floor insulation in the Passivhaus building model suggested more cooling energy demand. This finding in PHPP was emphasized by IES VE analysis, where the removing the floor insulation from the Passivhaus building model were able to reduce the cooling energy.

The analysis on the effectiveness of floor insulation in the Passivhaus building was discuss on the Chapter Eight.

This thesis conclusion is written in Chapter Nine. This chapter are summarized the findings and also describing the uncertainties and limitations on the research. On this chapter, the raised research questions are answered based on the finding on the research. The suggestion for further work is become the closing part of this thesis.

Chapter Two

2 ENERGY EFFICIENCY IN BUILDINGS

2.1 Overview

There is a growing indication that carbon dioxide emissions from the burning of fossil fuels are linked to global warming and climate change (IPCC, 2019). Climate change is a main reason for applying energy efficiency in the construction and building sector. Climate change in Indonesia greatly touches many aspects of the country, including economy, poor population, human health, and the environment. Indonesia has been recognized as one of the most vulnerable Asian countries due to climate change (Measey, 2010). The poor societies that live on the coast and those dependent on agriculture will be significantly affected by droughts, sea-level-rises, floods, and landslides.

As part of economic development, housing development must be supported by energy availability in order to accomplish sustainable growth in housing (International Energy Agency, 2013a). The building sector, in particular, presents one of the biggest opportunities for cost-effective energy consumption reduction. One of the methods to support the promotion of renewable energy is to design and build energy efficient housing that have a low energy demand (International Energy Agency, 2013a). In numerous parts of the world, buildings have long been built using local materials and local approaches to the climate. Modernization has caused higher densities in urban areas, the requirement of techniques for faster construction, and more inexpensive approaches that in many cases result in less efficient structures than old techniques for housing (International Energy Agency, 2013a). To support a better world, different agencies worldwide are promoting sustainable practices and guidance for developing countries (UNDP, 2019; UNEP, 2019). On the other hand, developed countries already have significant experience of energy-efficient, sustainable green building design, along with policies and regulatory codes. This section will deliberate the importance of energy efficiency, then be highlighted in the light of climate change. Finally, a brief summary of the current sustainable approaches developed in the Indonesia suggested by researches will be given, followed by a short review of an energy-efficient technologies and schemes that have spread worldwide.

2.2 Energy demand in Indonesia

Around 70% of the world's energy consumption in buildings comes from the residential sector and 30% from other building sectors in 2010, and this ratio is predicted to stay the same until 2050 (International Energy Agency, 2013a). Energy consumption for cooling is on the rise in Southeast Asia, with the number of air conditioners (AC) skyrocketing from almost 40 million units in 2010 to an expected figure of 350 million in 2040 (International Energy Agency, 2019a). Residential AC units are expected to contribute to more than 80% of the total stock by 2040, with Indonesia accounting for almost 50% of all air conditioners in the region by 2040 (International Energy Agency, 2019b). As a result, the consumption of electricity for cooling in buildings across the region increased 7.5 times from 10 terawatt hours (TWh) in 1990 to almost 75 TWh in 2017, bringing the share of cooling in total electricity consumption in Southeast Asia to almost 16%, up from 9% in 2018 (International Energy Agency, 2019a, 2019b).

The rising AC loads not only increased overall electricity demand, but also increased the daily and seasonal peak demands (International Energy Agency, 2019a). Cooling peak electricity requirement will increase from around 10% today to almost 30% by 2040 in Southeast Asia (Figure 2-1). Stronger actions to encourage the uptake of more efficient AC units is required to prevent the rise of electricity demand from cooling (International Energy Agency, 2013b).

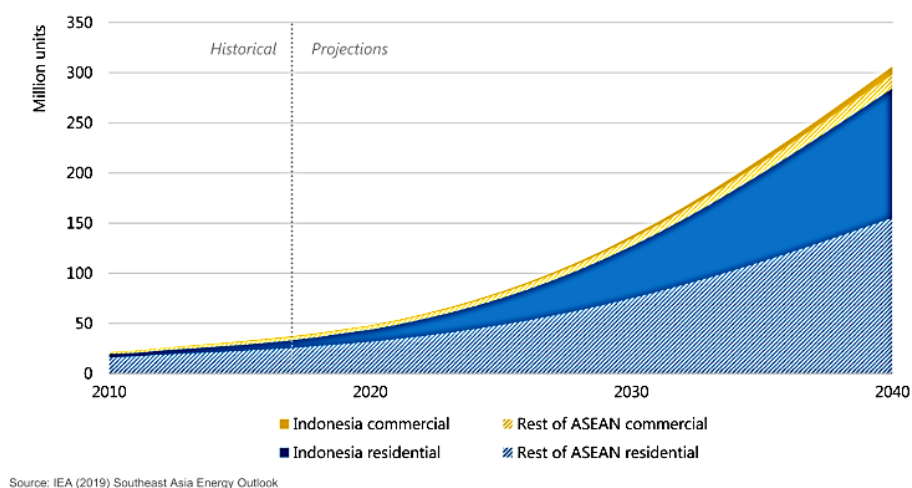


Figure 2-1 Stock of air conditioning units in Southeast Asia in the Stated Policies Scenario (STEPS) (IEA, 2019a).

2.3 Climate change and sustainability standards in Indonesia

Man-made interventions have been identified as one of the main contributors to greenhouse gas (GHG) emissions, which are directly linked to the causes of global warming (Jentsch et al., 2008). Improvement of the building stock is highly likely to decrease GHG emissions, as much energy is utilized within this sector (International Energy Agency, 2013b). Buildings, unlike systems or appliances, have a long existence, which may last for more than 50 years (Figure 2-2). The temperature changes projected through climate change are likely to overstretch the building systems in the future. This, in order, would be linked with accelerated energy consumption in the built environment (Li et al., 2013). Therefore, it would be best to plan buildings today to be ready for the changes of the future. The key challenge is to optimize the design of the overall building and the building envelope to meet the needs of the occupants while reducing energy consumption (International Energy Agency, 2013a).

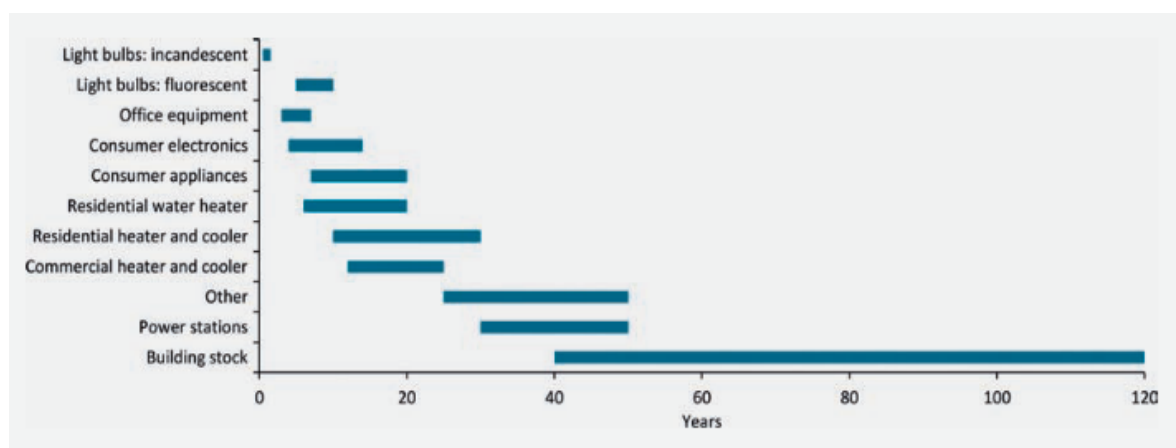


Figure 2-2 Building element lifespan (International Energy Agency, 2013b).

A tendency in the property market growth in Indonesia shows a growing trend that leads to the green concept. The regulatory framework for green buildings in Indonesia is relatively new. Indonesia has been starting a green concept through its Green Building Council, which is the concept of sustainable development as applied to the building industry (Anastasia, 2013). Green Building Council Indonesia (GBCI), formed in 2009, is an independent institution and non-profit organization that is fully dedicated to the education of the public in applying best practices and enable the transformation of the global sustainable construction industry (GBCI, 2014). There are several policy instruments which are connected to sustainability in building, construction and environment (Anastasia, 2013). With these policy instrument, it is

expected that the construction of buildings, houses and existing buildings will lead to a more sustainable development.

Indonesia has issued legal instruments to encourage the implementation of green buildings. The Minister of Public Works and Housing of Indonesia published a regulation (Regulation No. 2 of 2015) that covered essential elements of green buildings, such as building life cycle and sustainable environment in new and existing buildings (KemenPUPR, 2015a). The minister regulation encourages the implementation of energy efficiency and the reduction of GHG emissions in the Indonesian construction sector. But the regulation stated that the requirement for housing project under 300m² was voluntary (KemenPUPR, 2015b). Building certification can be either voluntary or mandatory, although mandatory certification is claimed to be more successful, as it fully achieves its set targets (Casals, 2006). Besides the Minister regulation, the 2002 building law also supports green building development. Although the 2002 building law does not clearly state green features of a building, the building law indicated that energy efficiency in AC and lighting systems was required to fulfil building occupants' health and comfort requirements, and such installations shall consider building energy savings principles. Table 2-1 lists the set of requirements for Indonesian sustainable housing based on the effort to improve domestic environments that are have been conducted in Indonesia (Larasati, 2001).

Table 2-1 Requirements for Indonesian Sustainable Housing (Larasati, 2001)

Aspects of sustainability	Set of requirements for Indonesian Sustainable Housing.
Energy	Applying the passive design strategy increasing the use of alternative energy sources.
Material	Employing construction principles for wet-tropical areas increasing the use of alternative (local) materials.
Water	Re-using water harvesting rainwater and purifying surface water and soil water.
Indoor environment	Popularizing the "healthy house" campaign.
Surrounding environment	Improving housing infrastructure. Self-initiated communal activities.
Economic	Upgrading facilities of existing settlements self-supportive financial system.
Social-cultural	Considering the gap among the levels of society. Considering the Indonesian communal way of living.

2.4 Thermal comfort and cooling in tropical buildings

Research has been conducted in several big cities in Indonesia, such as Jakarta, Surabaya, Bandung, and Jogjakarta. Studies of natural ventilated buildings suggested that it is very difficult to achieve thermal comfort, mainly in new built apartments (built after 2005), particularly when the units are facing west (Alfata et al., 2015; Karyono, 2000; Sujatmiko et al., 2015). These researches indicate that when the building is well-ventilated during daytime, indoor air temperatures was about 3.1 to 3.8°C lower than the outdoors during peak hours (Alfata et al., 2015; Feriadi and Wong, 2004; Karyono, 2000; Sujatmiko et al., 2015). The condition was worse for new apartments, where indoor temperatures were equal to or even higher than the corresponding outdoor air temperatures. Even with the high-level of apartment unit, low wind speeds (between 0.01 – 0.03 m/s) were still recorded internally, and so air flow was not effective to support the thermal comfort in rooms (Sujatmiko et al., 2015).

Evaluation of thermal comfort using the adaptive comfort equation showed that under full-day ventilation and night ventilation conditions, thermal comfort can be achieved over 52%-66% of the day only, and it was difficult to achieve thermal comfort without relying on air-conditioning for new apartments (Alfata et al., 2015). A study on residence in Surabaya – Indonesia found that the occupants was lived under relatively hot conditions both day and night (Uno et al., 2012). The research found that living room temperature reach 32.4°C at 14:00, and the bedroom temperature stay above 28°C during the nighttime.

The passive strategies to bring comfort into buildings are by basic methods including the use of shading, solar orientation and other building designs to reduce solar gain and promote natural ventilation to make the interior cool (Alfata et al., 2015). The other method is by using an electric fan or air conditioning, which is much more effective in reducing temperatures to provide thermal comfort but at an increased energy and economic cost (International Energy Agency, 2018; Sujatmiko et al., 2015). Improvement in the residential sector is important to reduce global energy demand (International Energy Agency, 2013a).

In hot-humid climates such as Indonesia, the use of air conditioners has increased, not only in offices but also residences (Uno et al., 2018). In hot climates it was also shown that people have a preference towards cooler environments as compared to what the neutral

temperature has shown (Feriadi and Wong, 2004). Properly designed ventilation, adequate solar protection, building inertia and insulation were able to lower room temperatures, but the study suggested the room still need to use air conditioning to bring comfort to the occupants (International Energy Agency, 2008). Residence with AC had a tendency to turn 'ON' the AC during the night time for at least 7 hours to achieve comfortable sleeping time (Mori et al., 2018).

The energy performance of building envelope components such as floors, roofs, ceilings, windows and doors, including external walls, is critical in defining how much energy is needed for heating and cooling (Djamila et al., 2013; International Energy Agency, 2013a). Common problems in many housing projects include leaky windows causing draughts, glare from inappropriately oriented or un-shaded windows, and excessive heat gain from east- or west-facing windows. Leaky and uninsulated walls and roofs result in the cooling equipment's inability to maintain the desired temperatures and leads to high energy bills and uncomfortable environments. It is vital to ensure new buildings use the most efficient technologies, as retrofits can be difficult and cost-prohibitive.

For a hot and humid climate, besides air temperature, humidity is the issue that needs attention to achieve thermal comfort. Therefore, the use of dedicated dehumidification systems is growing, especially in developing countries with very humid climates (International Energy Agency, 2018). For buildings with improved envelopes with higher thermal resistance, humidity control may account for a larger portion of cooling loads. ACs effectively act as dehumidifiers by reducing the temperature of a quantity of humid air that causes the humid air to condense its moisture in the cooling system evaporator or air-handling unit. Dehumidification on its own, without lowering ambient indoor temperatures, can often improve comfort in buildings at far lower cost than using ACs.

Research on an air-conditioned building has found that air-conditioning will increase energy demand, but thermal insulation (on wall and roof) can reduce energy demand (Andarini et al., 2009). The building envelope controls the amount of energy required to heat and cool a building, and consequently is required to be optimized to keep heating and cooling loads to a minimum (International Energy Agency, 2013b). A high-performance building envelope in a cold climate demands just 20% to 30% of the energy needed to heat the current average building, while in hot climates, the energy savings potential from reduced energy

requirements for cooling are expected to be between 10% and 40%. The priority for countries with hot climates should be highly reflective external surfaces, in order to reduce the need for cooling (International Energy Agency, 2013b).

2.5 Energy saving standard for buildings in a hot and humid climate

In the past decades, the energy-efficient buildings have become a topic of interest to architects and designers. The topics have spread rapidly within Europe and developed parts of the world, with the main intention of reducing energy consumption and GHG emissions (Allouhi et al., 2015). In the recent study that examined the historical evolution of energy-efficient buildings, indicate that the definition of an energy-efficient building could be linked with the type of examined performance criteria (Ionescu et al., 2015). This comprised energy consumption aspects, emission-related aspects, economical aspects and the period of evaluation. Therefore, not an easy task to limit energy efficiency standards or to rigorously group them within a single category, as in some situations the definition may have similarity between a number of categories.

In 2011, the Community's Intelligent Energy Europe program issued a report, which was based on a survey, to define high performance buildings and energy-efficient buildings in the EU. There are 23 terms were found to be associated with high performance buildings in the region, with some terms used in more than one country, such as: low energy house (13 of 14 countries), passive house (11) and energy saving house (7) (Erhorn and Kluttig, 2011). There are significant differences in consumption of all building's standards due to user behavior, including on the case of identically constructed buildings. The consumption of sufficiently large number of identically constructed homes are needed, so that utilization-dependent influences can be averaged out, thereby enabling a comparison of the building quality (Peper and Feist, 2015). Figure 2-3 indicated that the overview of measurement results from 41 low energy houses and a total of 106 Passivhaus homes in Germany. It shows how the Passivhaus building are able to perform better compared to low energy house. In the literature, the zero energy building and Passivhaus buildings was also linked to the fact that a zero energy house needs to be constructed in a highly energy-efficient manner, which was found to be promptly addressed in the Passivhaus standard (Carlucci et al., 2013).

The Passivhaus design's general principles in central Europe was characterized by strictly minimized or reduced heat losses, the use of passive solar energy and, for the summer is by using solar control and night ventilation (Schnieders et al., 2019). The strategy of minimized heat flows can also be used successfully in other climates in and outside Europe with adaptation on the components and solutions for the climate (Rongen, 2012). The hot climates issues are the ambient temperatures and humidities that exceed the desired indoor conditions for extended periods (Schnieders et al., 2019). The details of Passivhaus construction vary on the local climate, the character and orientation of the building layout, the shading situation, etc. It is therefore necessary to determine the required component quality in each individual case by using the corresponding design tools (Schnieders et al., 2015).

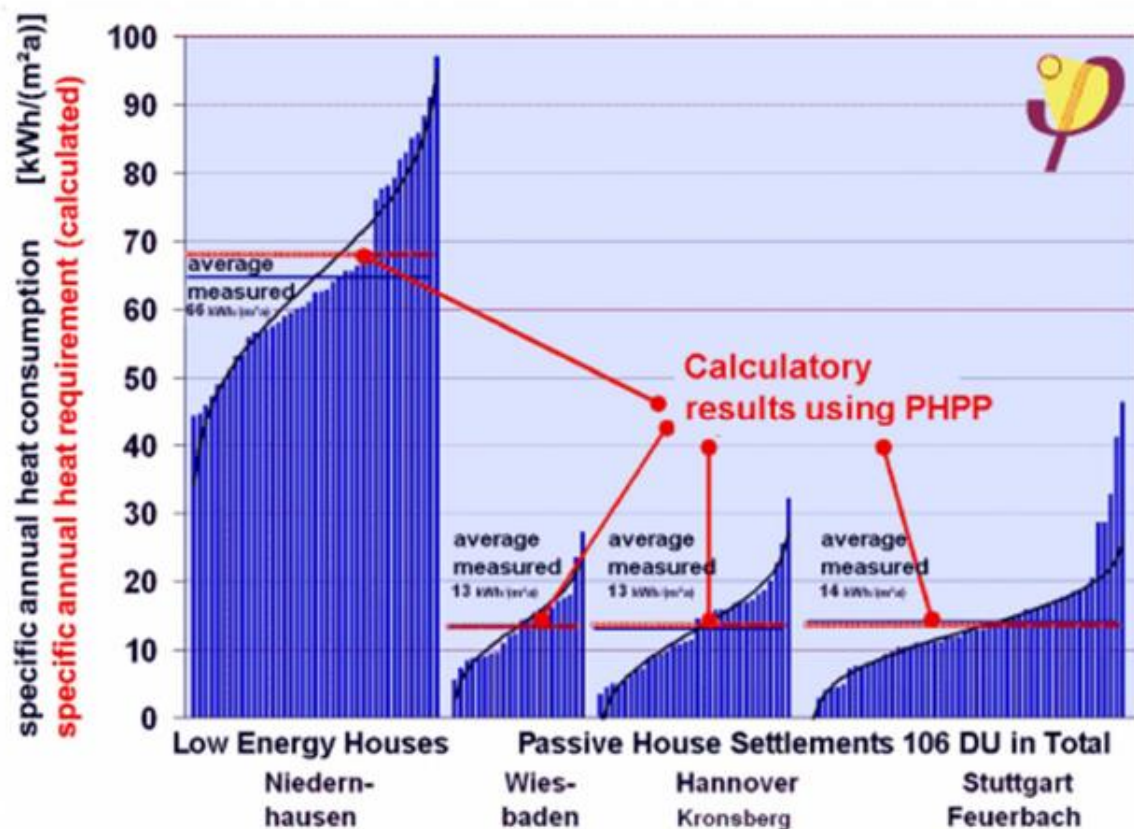


Figure 2-3 Overview of consumption measurements. This diagram summarizes the measured heat consumptions from four housing estates, a low-energy settlement (left) and three Passive House settlements (Peper and Feist, 2015).

The analysis of Passivhaus in different climate was done by undertake a research project 'Passivhaus for different climates' together with the Passive House Institute (PHI) and Prof. Dr Feist, Darmstadt, Germany (Rongen, 2012). On the paper, the site chosen to represent

Passivhaus building with hot and humid climate was in Dubai, and the analysis was shows that the model energy consumption for cooling was 40kWh/m²a, and 10kWh/m²a for dehumidification. But based on Köppen Climate Classification, subtype for Dubai climate's is "Bwh" (Tropical and Subtropical Desert Climate) (Kottek et al., 2006). In this case the Passivhaus model does not represent the Passivhaus in hot and humid climate.

An initial study about Passivhaus standard application in a hot and humid climate was made by creating a study that attempts to develop a new predictive thermal comfort standard that is suitable for Indonesian people in regard to the Passivhaus standard (Santy et al., 2016). The continuance study made by the writer was investigation on the climate characteristics of Indonesian regions using an Olgyay Bioclimatic chart, a Givoni–Milne Bioclimatic chart and a Mahoney Table at the pre-design stage in the development of a Passivhaus design standard for residential house construction in Indonesia (Santy et al., 2017). The findings of this initial research about Passivhaus in tropical climate regions were:

1. The occupants' comfort temperature should be redefined, due to a wider range of mean daily temperatures observed in the study (Santy et al., 2016).
2. Passive design strategies such as natural ventilation and shading devices, buildings oriented north-south, open spacing for protection from hot wind, single banked room for permanent provision of air, 20%–35% of wall area openings at body height, protection of the openings from rain and direct sunlight, protection from heavy rain were important to overcome temperature and humidity problems (Santy et al., 2017).

The initial study from Santy et al. in 2017 was based on tools that investigate of a strategy for designing buildings that correspond to the climate. The recommendation given was mainly the passive strategies that need to be applied into the building design to reduce the discomfort hours. The application of Passivhaus standard was not studied in the Santy et al. research.

This thesis was developed to study the Passivhaus application into the building that is built in hot and humid climates. The research in this thesis will be based on the analysis of building performance when the Passivhaus standard is applied to a typical dwelling in the Jakarta Metropolitan Region. The analysis in this thesis was achieved by creating a Passivhaus building model and studying the building performance under a hot and humid climate. The analysis

includes the building potential energy saving compared to a typical housing in Jakarta-Indonesia in term of cooling energy, the benefit of applying Passivhaus standards in tropical building, and the optimum way on applying the Passivhaus standard in building with hot and humid climate.

2.6 Summary

Energy efficiency in the built environment has become a subject of interest to many architects and engineers. Energy efficiency not only regulates energy use, but also mitigates GHG emissions and assures better indoor thermal comfort. Numerous studies have been carried out by researchers around the world to measure energy-efficient processes through parametric and post-occupancy studies. Other research is focused on establishing an outline to pave the way towards the sustainability of energy-efficient building and the measurement of how efficient a building.

The examined studies indicated that energy efficiency could be achieved through optimizing the building envelope and its systems. Through the literature review, the analysis found that thermal insulation can reduce energy demand in housing. On the other hand, natural ventilation in housing in big cities in Indonesia was not able to achieve thermal comfort. The study found that air-conditioning is needed to create thermal comfort to the building. Since the cooling will increase the energy demand, the study on the energy saving through optimizing the building envelop is important.

The next chapter will shed light on one of the fastest-growing energy-efficient standards – the Passivhaus standard. More than 50,000 buildings have been built around the world following this standard, although most of them have been constructed in Europe.

Chapter Three

3 THE PASSIVHAUS STANDARD

3.1 Overview

This chapter gives a brief background to the establishing of the Passivhaus standard. The Passivhaus standard was launched in May 1988, developed from low energy house to the Passivhaus that is known now, and is one of the world's most aggressive to radical energy reduction strategies for low energy buildings (International Passive House Association, 2013). The word Passivhaus will be used to refer to a house built to the Passive House Institute (PHI) specifications as detailed in this chapter. This is to avoid any possible misperception with "passive house" that is used in the generic sense of a low energy house using the principles of passive design, characteristically integrating a significant thought of passive solar design. Passive design strategies exploiting solar and internal gains to balance heat gain/losses due to transmission and ventilation, while Passivhaus approach permits the use of mechanical cooling/heating with certain limitations (Tronchin et al., 2018).

3.2 The Passivhaus Definition and Historical Background

"Passivhaus" was launched in May 1988 during a research period at the University of Lund in Sweden, and in 1990/91, the world's first Passivhaus was built (International Passive House Association, 2013). Four terraced house residential units were built in Darmstadt-Kranichstein, Germany using insulated window frames, reduced thermal bridges and CO₂-regulated ventilation. An accompanying monitoring programme provided information about super-insulated building components, windows, ventilation heat recovery, user behavior, indoor air quality, amount of internal heat sources and much else. This analysis became baseline to the development of the Passivhaus standard.

"A Passivhaus is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air" (Feist, 2016).

The Passivhaus Institute has indicated that the Passivhaus is not a brand name, but a construction concept that can be applied by anyone and that has stood the test of practice (Feist, 2007). Passivhaus standard assured indoor air quality, durability, and thermal comfort in the building. The functional definition of a Passivhaus, states that: *"A Passive House is a building in which thermal comfort can be guaranteed solely by heating or cooling of the supply*

air which is required for sufficient indoor air quality without using additional recirculated air” (McLeod et al., 2013). Generally, the Passivhaus standard delivers excellent cost-effectiveness, especially in the case of new build.

The German Passivhaus standard, which was originally developed to reduce winter heat losses from north European buildings, is based on the concept of an air-tight envelope. The success in the first Passivhaus projects, with very low energy consumption and high thermal comfort levels, has stimulated the spread of the Passivhaus standard to other countries in Europe and beyond (Passivhaus Trust, 2013). The Passivhaus Institute indicate that Passivhaus certified buildings have spread throughout the world. In the database of Passivhaus compiled by iHPA, Passivhaus Institute and Affiliates, there have been thousands of single detached family houses registered as Passivhaus in the several countries in Europe, and there are also some in the USA, East Asia, and Australia (Passivhaus Dienstleistung, 2019). Even though the initial developments were made within Central and Northern Europe, the findings suggested that the market for Passivhaus should not just be limited to Central Europe, and that the ultra-low energy standard could be a feasible option in different climates (Schnieders and Hermelink, 2006).

Thermal comfort in a Passivhaus building is achieved mainly by passive measures, for instance high levels of insulation, excellent airtightness, good indoor air quality, minimal thermal bridges and a whole house mechanical ventilation system with highly efficient heat recovery (Passipedia, 2015). Applying the Passivhaus building standard can preserve stable interior temperatures, but in tropical climates, with high temperature and high humidity, its airtight envelope might hinder the removal of excess moisture. The Passive-On study forecast a number of issues related to Passivhaus criteria for warmer climates (eERG, 2018). These included the introduction of a limit for energy demand for summer cooling, a relaxed infiltration rate and an indoor comfort temperature that coincided with adaptive thermal comfort standards. The Passivhaus standard application must accurately consider moisture balances and the attendant latent loads on the building with a hot and humid climate.

3.3 Passivhaus Criteria and Requirements

Passivhaus buildings are branded by an especially high level of thermal comfort with minimum energy consumption (Passipedia, 2015). The Passivhaus standard’s commitment is to create

a sustainable construction concept that provides affordable, high-quality buildings as well as comfortable, healthy living conditions (Sassi, 2013). The existence of a well-defined and specified set of guidelines to follow has further encouraged the adoption of the standard in buildings around the world. The Passivhaus standard is mostly considered to be a low energy building performance standard, that is characterised by super insulated, airtight envelopes, the use of mechanical ventilation with heat recovery (MVHR), and optimal use of passive solar gains.

The general principles of Passivhaus can be seen in Figure 3-1. According to the Passivhaus Institute, there are five basic principles that need to be applied for the construction of Passivhaus building (Feist, 2016):

- **Thermal insulation**
Superinsulation. All opaque building components of the exterior envelope of the house must be very well-insulated. Transmission losses are limited through the provision of a high-performance building envelope. The heat transfer coefficient (U-value) of the external walls is typically in the range 0.1 to 0.15 W/(m²K). For most cool-temperate climates, this means a U-value of 0.15 W/(m²K) at the most, i.e. a maximum of 0.15 Watts per degree of temperature difference and per square metre of exterior surface are lost.
- **Passive House windows.**
High-definition glazing and well-insulated frames are required by the Passivhaus Institute. The window frames must be well insulated and fitted with low-e glazing filled with argon or krypton to prevent heat transfer. For most cool-temperate climates, this means a U-value of 0.80 W/(m²K) or less, with g-values around 50% (g-value= total solar transmittance, proportion of the solar energy available for the room).
- **Mechanical Ventilation Heat Recovery (MVHR)**
Efficient heat recovery ventilation is key, allowing for a good indoor air quality and saving energy. MVHR systems can be run only when the building needs heating, allowing the building to be free running the rest of the year. In Passivhaus, at least 75% of the heat from the exhaust air is transferred to the fresh air again by means of a heat exchanger. MVHR also offers the opportunity for cooling when summer temperatures result in excessive heat.

- Airtightness of the building

Uncontrolled leakage through gaps must be smaller than 0.6 of the total house volumes per hour during a pressure test at 50 Pascal (both pressurised and depressurised).

- Absence of thermal bridges

All edges, corners, connections and penetrations must be planned and executed with great care, so that thermal bridges can be avoided. Thermal bridges which cannot be avoided must be minimised as far as possible.

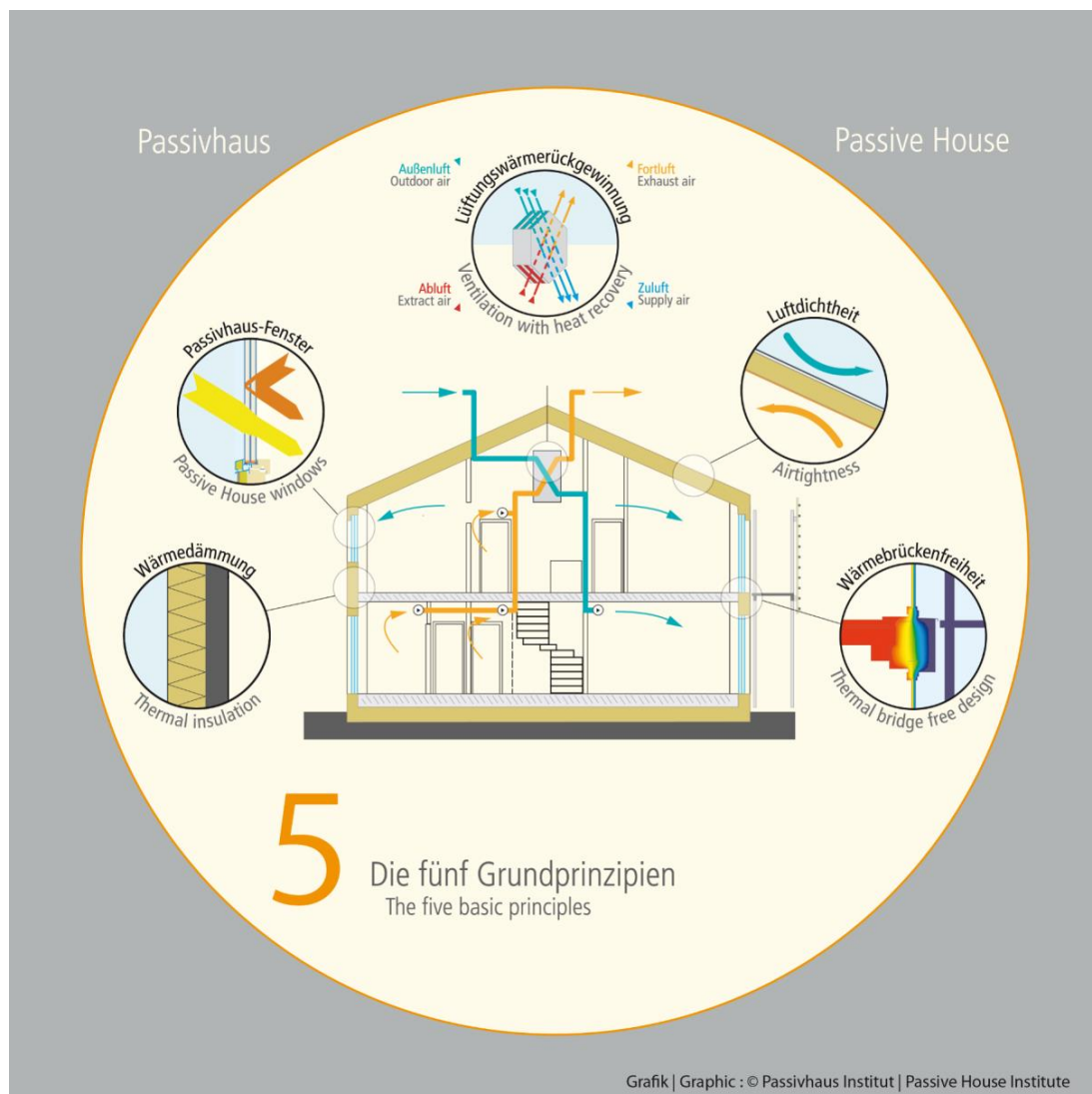


Figure 3-1 Diagram of general Passivhaus concept (Feist, 2007)

The Passivhaus criteria (Table 3-1) will be achieved through intelligent design and implementation of the all the above 5 Passive House principles (Feist, 2007). The Passivhaus Institute creates different approaches to the Passivhaus concept, such as: Passive House

Classic, Plus or Premium can be achieved depending on the renewable primary energy (PER) demand and generation of renewable energy (Passive House Institute, 2016). Evidence of compliance with the criteria shall be provided using the Passive House Planning Package (PHPP) with the application of the boundary conditions.

Table 3-1 Passivhaus Criteria (Passive House Institute, 2016)

				Criteria ¹	Alternative Criteria ²
Heating					
Heating demand	[kWh/(m²a)]	≤	15	-	
Heating load ³	[W/m²]	≤	-	10	
Cooling					
Cooling + dehumidification demand	[kWh/(m²a)]	≤	15 + dehumidification contribution ⁴	variable limit value ⁵	
Cooling load ⁶	[W/m²]	≤	-	10	
Airtightness					
Pressurization test result n ₅₀	[1/h]	≤	0.6		
Renewable Primary Energy (PER)⁷					
			Classic	Plus	Premium
PER demand ⁸	[kWh/(m²a)]	≤	60	45	30
Renewable energy generation ⁹ (with reference to projected building footprint)	[kWh/(m²a)]	≥	-	60	120
			±15 kWh/(m²a) deviation from criteria... ...with compensation of the above deviation by different amount of generation		

¹ The criteria and alternative criteria apply for all climates worldwide. The reference area for all limit values is the treated floor area (TFA) calculated according to the latest version of the PHPP Manual (exceptions: generation of renewable energy with reference to projected building footprint and airtightness with reference to the net air volume).

² Two alternative criteria which are enclosed by a double line together may replace both of the adjacent criteria on the left which are also enclosed by a double line.

³ The steady-state heating load calculated in the PHPP is applicable. Loads for heating up after temperature setbacks are not taken into account.

⁴ Variable limit value for the dehumidification fraction subject to climate data, necessary air change rate and internal moisture loads (calculation in the PHPP).

⁵ Variable limit value for cooling and dehumidification demand subject to climate data, necessary air change rate and internal heat and moisture loads (calculation in the PHPP).

⁶ The steady-state cooling load calculated in the PHPP is applicable. In the case of internal heat gains greater than 2.1 W/m² the limit value will increase by the difference between the actual internal heat gains and 2.1 W/m².

⁷ The requirements for the PER demand and generation of renewable energy were first introduced in 2015. As an alternative to these two criteria, evidence for the Passive House Classic Standard can continue to be provided in a transitional phase by proving compliance with the previous requirement for the non-renewable primary energy demand (PE) of QP ≤ 120 kWh/(m²a). PHI may specify other national values based on national primary energy factors. The desired verification method can be selected in the PHPP worksheet "Verification". The primary energy factor profile 1 in the PHPP should be used.

⁸ Energy for heating, cooling, dehumidification, DHW, lighting, auxiliary electricity and electrical appliances is included. The limit value applies for residential buildings and typical educational and administrative buildings. In case of uses deviating from these, if an extremely high electricity demand occurs then the limit value can also be exceeded after consultation with the Passive House Institute. Evidence of efficient use of electrical energy for all significant devices and systems is necessary

for this with the exception of existing devices which have already been owned by the user previously and for which an improvement of the electrical efficiency by means of upgrading or renewal would prove uneconomical over the lifecycle.

⁹ Renewable energy generation plants which are not spatially connected to the building may also be taken into account (except for biomass use, waste-to-energy plants, and geothermal energy): only new systems may be included (i.e. systems which did not start operation before the beginning of construction of the building) which are owned by the building owner or the (long-term) users (first-time acquisition).

The requirements of the Passivhaus standard are very specific. In order to achieve certification as a Passivhaus, besides a high level of energy efficiency, Passivhaus buildings must offer an optimum standard of thermal comfort and a high degree of user satisfaction as well as protection against condensate related damage. In order to guarantee this, the minimum criteria mentioned below must also be complied with in addition to the criteria showed on the Table 3-1 (Passive House Institute, 2016):

- Frequency of overheating: Percentage of hours each year with indoor temperatures above 25°C must be $\leq 10\%$ if without active cooling, and if building using active cooling, cooling system must be adequately dimensioned.
- Frequency of excessively high humidity: Percentage of hours each year with absolute indoor air humidity levels above 12 g/kg if the buildings are without active cooling is $\leq 20\%$ and with active cooling is $\leq 10\%$.
- Minimum thermal protection: If a construction component fails to achieve the thermal comfort requirements in individual cases, a red warning symbol appears next to it in the PHPP (there is no such warning for the moisture protection requirement in PHPP). They apply for each individual building component on its own (e.g. wall build-up, window, connection detail).
- Occupant Satisfaction: Exemptions to the below requirements are possible in justified cases if there is no significant likelihood of occupant satisfaction being impaired.
 - All rooms with prolonged occupancy must have at least one operable window.
 - It must be possible for the user to operate the lighting and temporary shading elements. Priority must be given to user-operated control over any automatic regulation.
 - In case of active heating and/or cooling, it must be possible for users to regulate the interior temperature for each utilisation unit.

- The heating or air-conditioning technology must be suitably dimensioned in order to ensure the specified temperatures for heating or cooling under all expected conditions.

Given that the Passivhaus concept initially evolved in the cooler climate of northern Europe, the Passivhaus criteria were mostly aimed at buildings that required heating. In Table 3-1 can be seen that the criteria for the cooling is depend on the dehumidification contribution. Variable limit values for the dehumidification fraction are subject to climate data, necessary air change rate and internal moisture loads (calculation in the PHPP) (Passive House Institute, 2016). For buildings in hot and humid climates, that require cooling and dehumidification, the cooling demand and cooling load criteria are still dependent on the calculation in the PHPP software. With the development and spread of the Passivhaus standard to a wider climatic context, unavoidable improvements to the initial criteria were foreseen and inevitable.

3.4 The Passivhaus in Europe

The first pilot project in Darmstadt was successfully in creating a low energy building, and this encouraged more buildings to be built to the Passivhaus standard (International Passive House Association, 2013). The initial spread of the standard was to different parts of Europe which were located in mild climates. Today, the spread of Passivhaus buildings is still predominantly in Europe (Figure 3-2). Most of the Passivhaus buildings based on the Passivhaus database (Passivhaus Dienstleistung, 2019) are, at present, found in Germany (49%) and Austria (22%). This is perhaps because the Passivhaus standard had been welcomed very early in Austria and German, and the pilot projects in both of the countries were developed and opened to the public (Müller and Berker, 2013). The fast development was also supported by the building components that may have become more affordable after the wider spread of the standard.

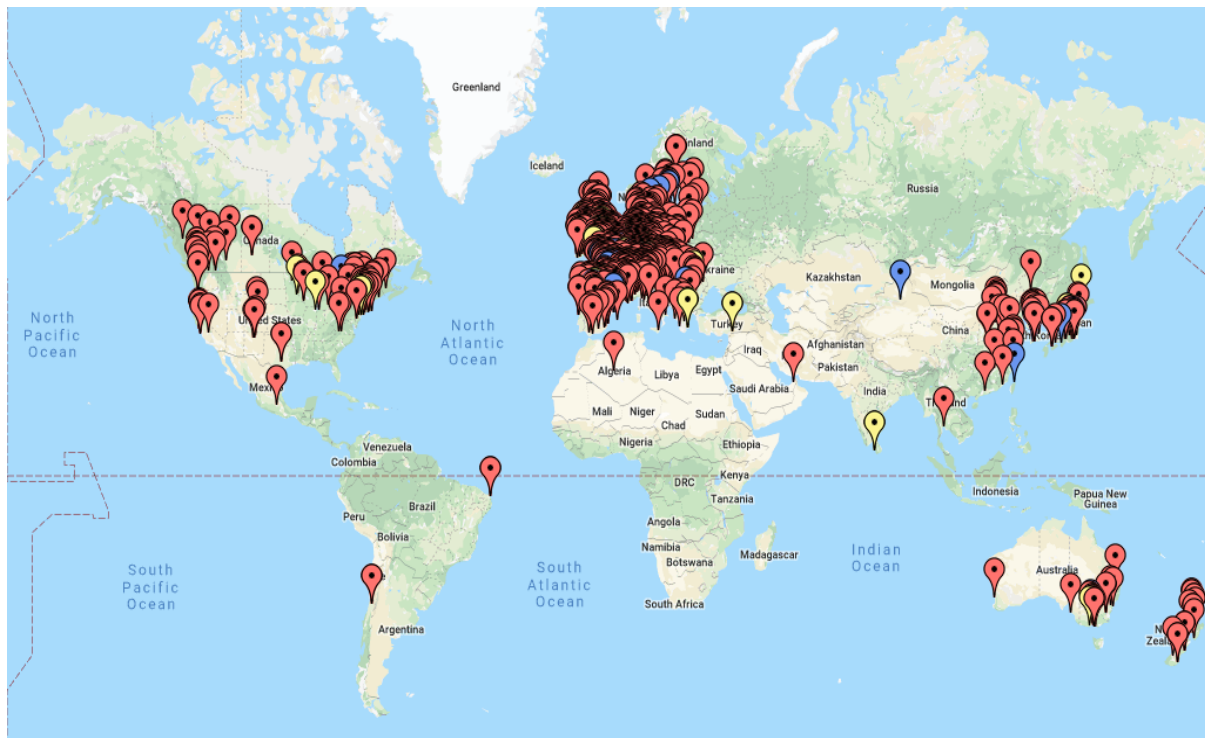


Figure 3-2 Passivhaus projects maps around the world (Passivhaus Institute, 2019)

3.4.1 The world's first Passivhaus, Darmstadt-Kranichstein, Germany

The first Passivhaus building that became the initial source to develop the Passivhaus standard was introduced at Darmstadt University in the state of Hessen in Germany (Passivhaus Institut, 2019) (Figure 3-3). A scientific working group was set up for this project and was funded and directed by Hessian Ministry for economics and technology (HMWT). The American architect Robert Hastings who had previously worked on many super insulated housing projects in the US was also supported the design work. The project making up a small row of terraced houses in Kranichstein, consist of four family homes with each building area was 156m². This project has since become known as the 'Experimental housing Darmstadt Kranichstein K7' project. The architects for this K7 project were Professors Bott, Ridder and Westermeyer. They were working together with Professors Wolfgang Feist and Bo Adamson to produce occupied homes with as close to zero heating requirements as possible. The design features are listed in Table 3-2.



Figure 3-3 The first Passivhaus building (Passivhaus Institut, 2019)

Table 3-2 Design features of the Passive House in Darmstadt-Kranichstein (Passivhaus Institut, 2019)

Roof	U-value 0.1 W/m ² K
Wall	U-value 0.14 W/m ² K
Cellar Slab	U-value 0.13 W/m ² K
Triple Low-e Glazed Windows	U-value 0.70 W/m ² K
MVHR efficiency	80%

In addition to the above design features, a specially adapted well-adjusted supply air and exhaust air ventilation system with a highly efficient counter flow air-to-air heat exchanger was used, because at the time the fans consumed a very high electricity consumption (Passivhaus Institut, 2019). During the operation, the heat recovery rate measured was over 80%. The buildings also applied on-site solar thermal panels in addition to domestic hot water heating and ground source heat pumps. The blower-door tests after construction found the average air-permeability of the housing was 0.3ach⁻¹ @ 50 Pa, with no thermal bridge found by thermographic images. Due to the well-insulated and airtight sliding shutters, it was even possible to function one of the house units as a “zero-heating-energy house” without any heating in the years 1994 to 1996.

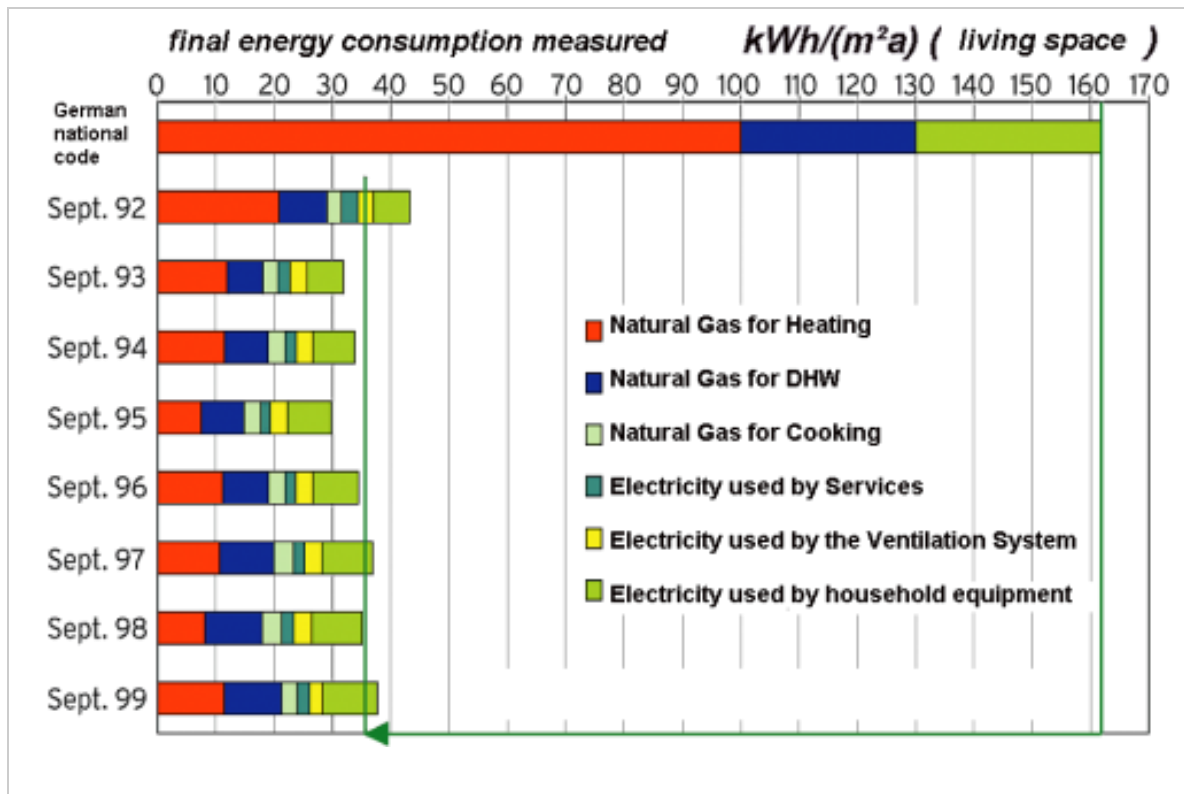


Figure 3-4 Results of the energy consumption measurements in the Passivhaus in Darmstadt-Kranichstein (Passivhaus Institut, 2019)

The Passivhaus in Kranichstein was completed in October 1991 and since then has been occupied by four families (Feist, 1998; Passivhaus Institut, 2019). The housing was initially extensively monitored with data being continuously gathered and was analyzed to produce annual energy consumption. From the graph in Figure 3-4 can be seen that the energy of this first Passivhaus building was reduced by 90% from German national code building, and the energy used remain constant throughout the following years. Measurement in 2010, the measured space heating demand stay at 10 kWh/(m²a) (heated living area) with the same four families are still occupy the houses. Very small maintenance has yet been undertaken and entirely building services remain the same as the original configuration.

The first Passivhaus in Darmstadt-Kranichstein had completely fulfilled the expectations placed in these prototypes. The excellent results shaped the foundation for the “Research Group for Cost-efficient Passivhaus” in 1996 (Passivhaus Institut, 2019). The Research Group team was forming a more simplified planning of Passivhaus, e.g. the Passive House Planning Package (PHPP). A bigger number of second generation Passivhaus pilot projects were built and the development of Passivhaus-suitable components was underway. The Research Group for Cost-efficient Passivhaus taking an important role in the exchange between building

physics and building practice. Since the overall building cost of the Kranichstein dwelling was 50% more than conventional housing built during the same period of time in Germany, the development of Passivhaus-suitable components was the next step to develop.

3.4.2 CEPHEUS – (Cost Efficient Passive Houses as European Standards)

After the successful development and monitoring of the Kranichstein test housing, this K7 project were used as a foundation to develop the proposal and performance specification for the CEPHEUS (Cost Efficient Passive Houses as European Standards) program in 1997. The CEPHEUS program intention was to develop a low energy, low cost building standard for Europe (CORDIS, 1997). The intension of CEPHEUS is testing the combination of the Passivhaus technologies, the drastic and cost-efficient reduction in energy demand at different building sites with different climates in Europe. In this scheme, 262 cost efficient dwelling units have been built with different building sites, different planners, different users and different construction types. Figure 3-5 indicates CEPHEUS sites, where one of the construction places was positioned in the immediate neighbourhood of the EXPO2000 World Fair and listed as an official EXPO2000 scheme. As part of the scheme, monitoring and dissemination of the projects was presented at the EXPO2000.

The CEPHEUS scheme, as a large-scale European initiative was used to demonstrate the likelihood of the Passivhaus concept and to establish strategies for the spreading of the concept as well as to create the fundamentals for a broad market overview of cost efficient Passivhaus. The following goals have been defines for the project (BMVIT, 2001):

- To establish the technical possibility of different building and types of construction by diverse architects and developers in some European countries at only slight additional cost (which are to be paid off by saving from the operation of the building)
- To observe the acceptance by investors and prospective buyers, and to study the user behaviour under realistic situations from a representative series of case studies
- To check the cost-efficient planning and construction of applying Passivhaus standards throughout Europe.
- To boost more activities in the energy and cost-efficient buildings, to push the marketing and development of innovative technologies that meet Passivhaus standard.



Figure 3-5 CEPHEUS sites (Feist et al., 2001)

The Passivhaus component that was used in the built CEPHEUS scheme buildings are listed in the Table 3-3. This component can be subsumed under five basic (Feist et al., 2001), that is:

1. Superinsulation: Exceptionally good thermal envelope in which preventing thermal bridging and air leakage.
2. Linking efficient heat recovery with additional supply air heating. To ensure occupant comfort in Passivhaus dwelling, supply air heating was regulated to deliver precisely the necessary air quantity for excellent indoor air quality. To transfer the heat

contained in the extracted indoor air to the incoming fresh air, a high-performance heat exchanger was used. Additional fresh air preheating in a subsoil heat exchanger is possible, which further reduces the need for supplementary air heating.

3. Passive solar gain was achieved by designing the main glazing areas are oriented to the south and are not shadowed. The glazing was designed to provide adequate daylight, covers about one third of the minimized heat demand of the house by having triple low emissivity glazing and super insulated frames. The benefit of these system is to let in more solar heat and reduce the solar heat they lose.
4. Fitting the Passivhaus dwelling with efficient appliances such as: efficient domestic appliances, hot water connections for washing machines and dishwashers, airing cabinets and compact fluorescent lamps, to achieve electric efficiency but without any loss of comfort or convenience. All building services are planned to function with maximum efficiency.
5. Fulfilling the energy demand with renewables energy by making the Passivhaus fully primary-energy and climate-neutral through balancing the energy consumption for space heating, domestic hot water and household electricity by renewable sources. The Passivhaus approach thus permits climate neutral new housing construction should be at prices within the normal market range.

The first three basic elements are crucial to the Passivhaus concept to fully minimize environmental impacts, and the other two are necessary (electric efficiency) or expedient (meeting remaining energy demand with renewables) supplements.

A comprehensive concept for quality assurance and evaluation was planned and implemented (Schnieders, 2003). The basic measurement programme for all houses were concentrates on the measurement parameters requisite to assess the principal goals of the project such as space heat requirement, final and primary energy consumption, and occupant comfort (Feist et al., 2001). The planning was using the Passive House Planning Package (PHPP) to avoid the needing of complex simulation techniques, however the simulations was still used for further issues relating to thermal comfort and the effects of different heat distribution systems. Advice sessions at the building sites and with the manufacturers were made to avoid and resolve numerous problems such as thermal bridging or condensation

problems. To all building, a 'blower door' under 50 Pascal positive and negative pressure differences was used to tests airtightness quality.

Table 3-3 Overview of the innovative components of the CEPHEUS sub-projects (Feist et al., 2001)

Cepheus-project		Building type			Con-struction		TFA	Breakdown of innovative technologies												
Sub-project No.	CEPHEUS sub-project title	Detached houses	Terraced houses	Multy-family houses	Solid + external insulation	Mixed construction	Lightweight construction	Treated floor area per DU (min-max) [m ²]	1. Superinsulation	2. Thermal bridge reduction	3. Airtightness	4. Subsoil air preheater	5. Hygienic ventilation	6. Heat recovery	7. Passive solar energy utilisation	8. Superwindows	9. Active solar energy utilisation (x=thermal; PV)	10. Innovative packaged building services	11. Efficient household appliances	12. Zero-energy-balance settlements
01	Germany, Hannover		32			x		75-120	x	x	x		x	x	x	x	x		x	x
02	Germany, Kassel			40	x			67-83	x	x	x		x	x	x	x	PV			
03	Sweden, Gothen-burg		20				x	138	x	x	x	x	x	x	x	x	x		x	
04	Austria, Egg			4	x			75-81	x	x	x	x	x	x	x	x	x		x	
05	Austria, Hörbranz		3		x			126-129	x	x	x	x	x	x	x	x	x	x	x	
06	Austria, Wolfurt			10		x		71-168	x	x	x	x	x	x	x	x	x		x	
07	Austria, Dornbim	1				x		125	x	x	x	x	x	x	x	x	x	x	x	
08	Austria, Gnigl			6		x		48-68	x	x	x		x	x	x	x	x		x	
09	Austria, Kuchl			25		x		60-136	x	x	x		x	x	x	x	x PV		x	
10	Austria, Hallein			31		x		53-87	x	x	x		x	x	x	x	x		x	
11	Austria, Horn	1				x		173	x	x	x	x	x	x	x	x	x		x	
12	Austria, Steyr		3		x			154-158	x	x	x	x	x	x	x	x	x		x	
13	Switzer-land, Lucerne		5				x	123	x	x	x	x	x	x	x	x		x	x	
14	France, Rennes			40	x			46-118	x	(x)	x		x	x	x	(x)	x		x	

The study's findings, at least during the first year of operation, that targeted a space heat energy requirement of 15kWh/(m²a) was already being met across the great majority of the measured CEPHEUS dwelling units (Feist et al., 2001). The subjective appraisals of users also indicate that occupant comfort is excellent in both winter and summer. The energy

consumption reduction for room heat is accounts for around 75% of the whole end energy consumption of private households and of approx. 40% of end energy consumption of all sectors in Central Europe. With the Passivhaus concept it has been possible to reduce the room heat primary energy consumption by more than 80% and the total primary energy consumption for heating, hot water and household electricity by 57% in the first heating period of the evaluated projects Figure 3-6. The comparison results between CEPHEUS dwelling to other buildings erected by the developers according to the locally appropriate building regulations, indicate that the extra costs of the building projects average less than 10%. From the above results, indicated that CEPHEUS projects in several European countries with a large number of dwelling units, and very different building types and constructions, has met its goals with cost-effective implement ability of the Passivhaus standard.

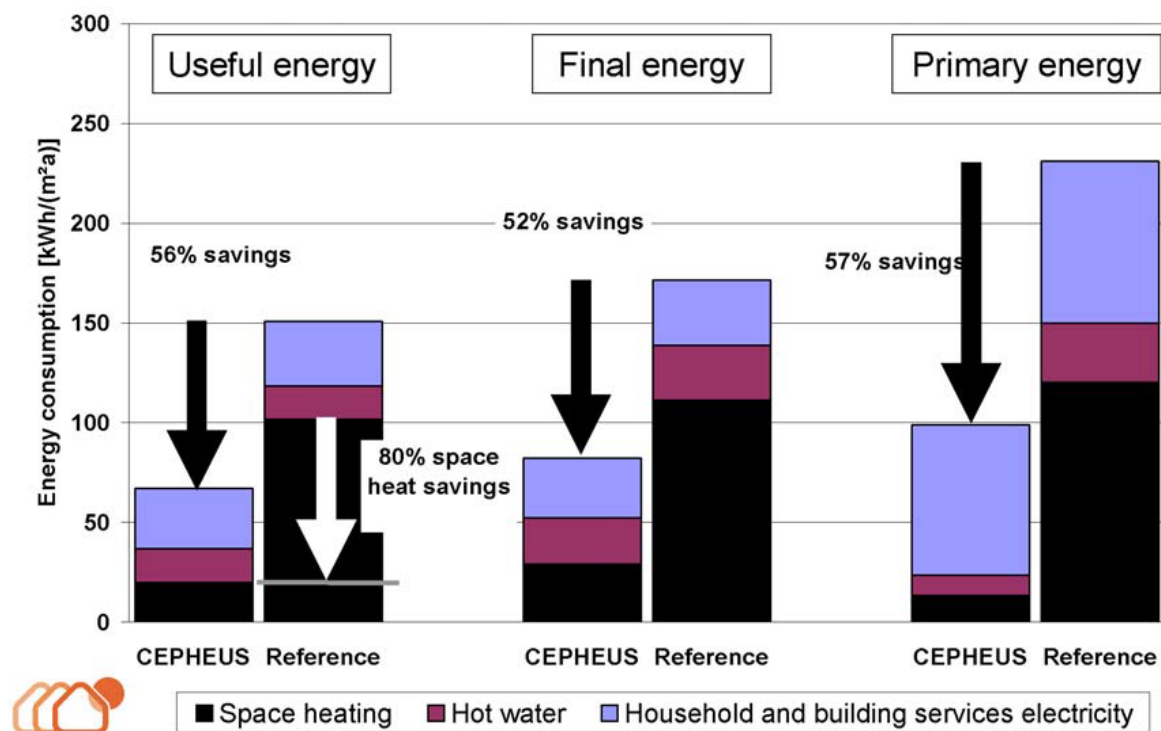


Figure 3-6 Comparison of the measured consumption levels of all CEPHEUS projects (floor-area-weighted mean) with the corresponding reference consumption levels (Feist et al., 2001).

3.5 The Passivhaus in different climate zones

The initial Passivhaus developments were made within the relatively mild climate of Central and Northern Europe (Feist, 1998). The success of the Passivhaus standard in that region, and its straightforward approach encouraged the Passivhaus development to other parts of the world. Studies had also suggested that Passivhaus could be a feasible option in other climate

types (Schnieders and Hermelink, 2006). In this chapter, three cases will be demonstrated to discuss the implications of the Passivhaus standard in hot climates. The first Passivhaus building is the Austrian embassy in Jakarta, Indonesia, the second is the Le-Bois house in Louisiana-USA, and finally an office building in Al Khawaneej, Dubai, UAE.

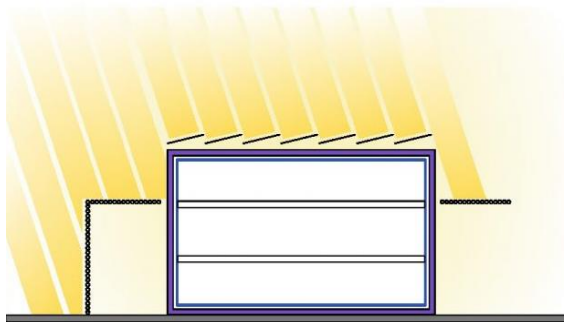
3.5.1 The Austrian embassy in Jakarta, Indonesia

The Austrian Embassy in Menteng (Figure 3-7), Jakarta is not only Austria's first green embassy, but is also known as the first green building in the city (Jesse, 2011). The approach used was of climate friendly architecture for hot and humid climates. The embassy resembles a sustainable design that is climate sensitive. The building design suggests a new approach to sustainable architecture in hot and humid climates.

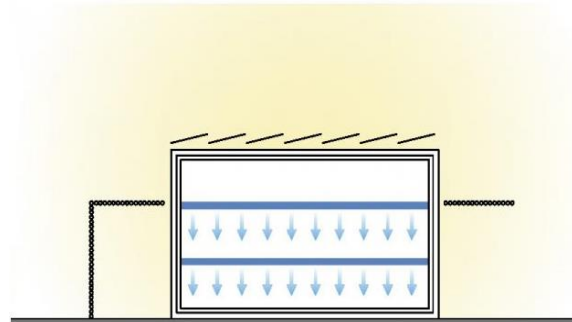
Vienna-based POS architecture had designed the building according to the Passivhaus standards (POS Architecture, 2019). Considerable attention was given to the climatic conditions of the region, resulting in a number of design strategies that helped to form the Passivhaus Austrian embassy. The embassy was specially adapted to Indonesia's hot and humid tropical climate such as a careful shading of all openings to ensure that glazed surfaces were located on the main axis façades, giving carefully attention to the ratio of the opaque to clear surfaces, and added solar protection to these surfaces (Figure 3-9). The glazed surfaces were deeply recessed and well insulated; timber screening was used to shade the walls and roof of the building. Passivhaus standards was achieved by constructing high thermal insulation standard for exterior walls, double glazed windows, an air-tight building shell, cooling via CCTC (concrete core tempering control), and a ventilation plant with energy recovery (Figure 3-8) (Austrian Embassy Jakarta, 2019). The building was achieving an airtightness level of 0.4 air changes per hour at 50 Pascals with a blower door test (Passive House Database, 2019). A design was set to guaranteed temperature of 25 °C, 60 % humidity, and a full and smooth supply with fresh air provides excellent and healthy indoor conditions for the staff.



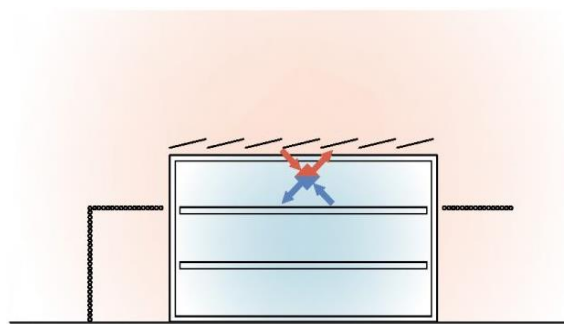
Figure 3-7 Austrian embassy Jakarta (POS Architecture, 2019)



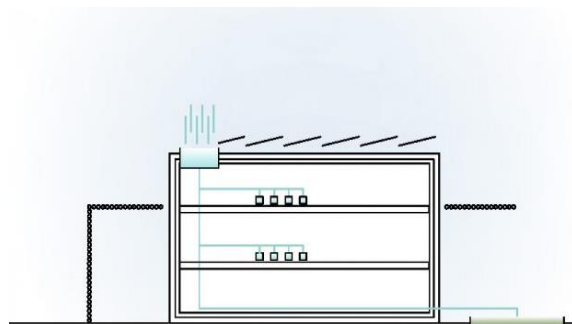
Thermal insulation:
 wall $U\ 0.3\ \text{W/m}^2\text{K}$, roof $U\ 0.1\ \text{W/m}^2\text{K}$
 2 panel heat/sun protection glazing $g\text{-value}\ 0.3\ \text{W/m}^2\text{K}$
 Airtight building envelope:
 low humidity/heat infiltration ($n_{50}=0,45$)



Interior cooling through component activation,
 (CCTC-Concrete Core Temperature Control)



Ventilation with cold and dry heat recovery



Rainwater collection for toilet flushing and garden
 irrigation

Figure 3-8 Austrian embassy Jakarta building's Passivhaus approaches diagram (POS Architecture, 2019)

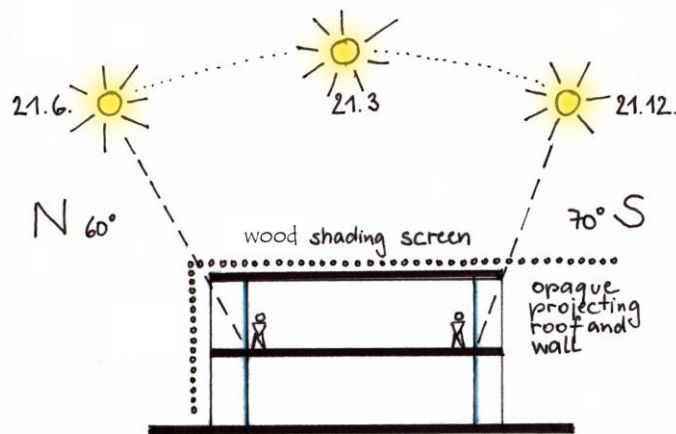


Figure 3-9 Austrian embassy Jakarta building orientation concept (POS Architecture, 2019)

The Austrian embassy covers a rough floor area of 1,100m² on two storeys and contains staff offices, meeting rooms, an auditorium as well as technical facilities (Oettl, 2014). The construction details of the building are:

- External wall was made of concrete and brick with 180mm thickness and 150mm mineral wool insulation,
- Interior wall was made of concrete or brick and plastered,
- The roof was built from 180mm reinforced concrete, 180mm mineral wool, two layers of waterproofing, and screed with a roughened surface layer (Andarini, 2010).

Cooling demand in the building using a CCTC system is using a thermo-active building system, where the thermal structure of the building was used to cool the building. The base load for the cooling supply is covered by a chiller. It provides gentle radiant cooling by pumping cool water into pipes cast inside the floor, instead of a cold air breeze from split units. This system reduced the need for conservative air-conditioning system and guaranteed a comfortable indoor environment. A ventilation system using a cooling recovery and dehumidification was used to deliver fresh air to all the office spaces in the building. A mean temperature of 25°C, and 60% humidity is guaranteed, together with a good supply of fresh air (Austrian Embassy Jakarta, 2019). It is found from the building thermal simulation, that the cooling energy demand and the dehumidification is accounted for 74.8 kWh/m². With this innovative design solution by POS architects, the reduction of total energy demand was 85% compared to a standard Jakarta office building, which is equivalent to a reduction of CO₂ emissions per year of 73 tons (Austrian Embassy Jakarta, 2019). Further the 96 m² Photovoltaic generator on roof top will cover 22% of annual electric power demand. The overall annual energy demand was estimated at 117.1 kWh/m² of treated floor area using the Passive House Planning Package.

So altogether Austria is building a New Embassy as an innovative approach to climate friendly architecture for hot and humid climates.

3.5.2 The Le-Bois house in Louisiana, USA

One of the certified Passive Houses in the southern USA is in Lafayette in Louisiana (Figure 3-10). The 120m² long and thin Passivhaus building depend on the design strategies of the area's camelback shotgun style to minimize eastern and western heat gain while maximizing southern and northern exposure (Goodman, 2012). The double-storey and three-bedroom student accommodation has the south-facing single-pitch roof reflects and maximizes the natural light that floods the house through the north-facing clerestory windows. Professor Corey Saft from the University of Louisiana was initiated the project, with the main purpose of experimenting with the possibility of adapting the Passivhaus concept in the hot humid region of southern USA (Defendorf, 2010).



Figure 3-10 204-House, in Lafayette, Louisiana (Defendorf, 2010)

To achieve the Passivhaus requirement, the architect chose the advanced framing techniques to increase R-value and reduce thermal breaks, by wrapping the house with polyisocyanurate insulation that is 50mm in the roof and 25mm in all others area. The building facade is a modified back-vented rainscreen designed to act as a whole-house sun shade while dealing

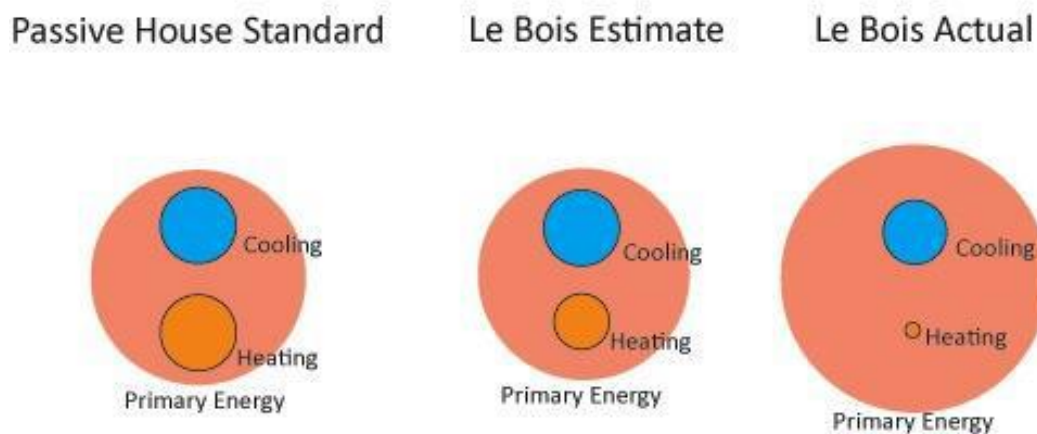
with moisture (Goodman, 2012). This rain-screen system ridding the building of much of the heat even before it gets to the insulated walls. The main HVAC system for the project is by using a 1-ton mini-split air-conditioning system and the Energy Recovery Ventilator (ERV). The architects also used an air-to-water heat pump as an addition for cooling and dehumidification and to deliver hot water. Inside the home, Type-X drywall, concrete counters, and tile in the bathrooms is used to store the cool in the summer and the warm in the winter. A 3.26kW thin film solar cell array integrated into the light-colored standing-seam metal roof. Each panel fits between the ridges of the building's standing seam metal roofing system and face south for maximum efficiency. The panels is efficient even in restricted shade conditions and with off-angle sun rays, take along the house net energy consumption near zero for much of the year (Design and Build With Metal, 2019). PHPP software result for the building shown in Figure 3-11 indicated that the house fulfilled the Passivhaus criteria (White, 2014).

After the construction process is complete, the house was undergoing 18 months of extensive monitoring (White, 2014). The actual measurements during this period concluded variable results, where the house actually used less energy for both cooling and heating compared to PHPP results. The energy comparison of actual measurement and PHPP result can be seen in Figure 3-12.

The table in Figure 3-12 indicated that measured cooling and heating energy use was lower than the PHPP calculation, but the contradictory things happen to primary energy. The measured primary energy was found 50% more than the PHPP calculation. If we look at the graph in Figure 3-13, there was an increase in net house energy used. The calculation of cooling system was based on the mini-split air-conditioning system, without include latent demand or energy used due to dehumidifier (White, 2014). From Figure 3-13 it can also be seen that in September there was an increase in energy needs when dehumidifier was installed.

Energy Demands with Reference to the Treated Floor Area				
Treated Floor Area:	1290	ft ²		
Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	2.52	kBTU/(ft ² ·yr)	4.75 kBTU/(ft ² ·yr)	Yes
Pressurization Test Result:	0.57	ACH ₅₀	0.6 ACH ₅₀	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	36.8	kBTU/(ft ² ·yr)	38.0 kBTU/(ft ² ·yr)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	17.4	kBTU/(ft ² ·yr)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	15.9	kBTU/(ft ² ·yr)		
Heating Load:	4.65	BTU/(ft ² ·hr)		
Frequency of Overheating:	40.4	%	over 77.0 °F	
Specific Useful Cooling Energy Demand:	4.69	kBTU/(ft ² ·yr)	4.75 kBTU/(ft ² ·yr)	Yes
Cooling Load:	3.83	BTU/(ft ² ·hr)		

Figure 3-11 LeBois House's PHPP Results (White, 2014)



	PHPP Specific Energy Use [kWh/m ² a]	Measured Specific Energy Use (Mar 2011 - Feb 2012) [kWh/m ² a]
Primary Energy	116	184
Cooling	15	10.6
Heating	8	0.6

Figure 3-12 LeBois House's results comparison (White, 2014)

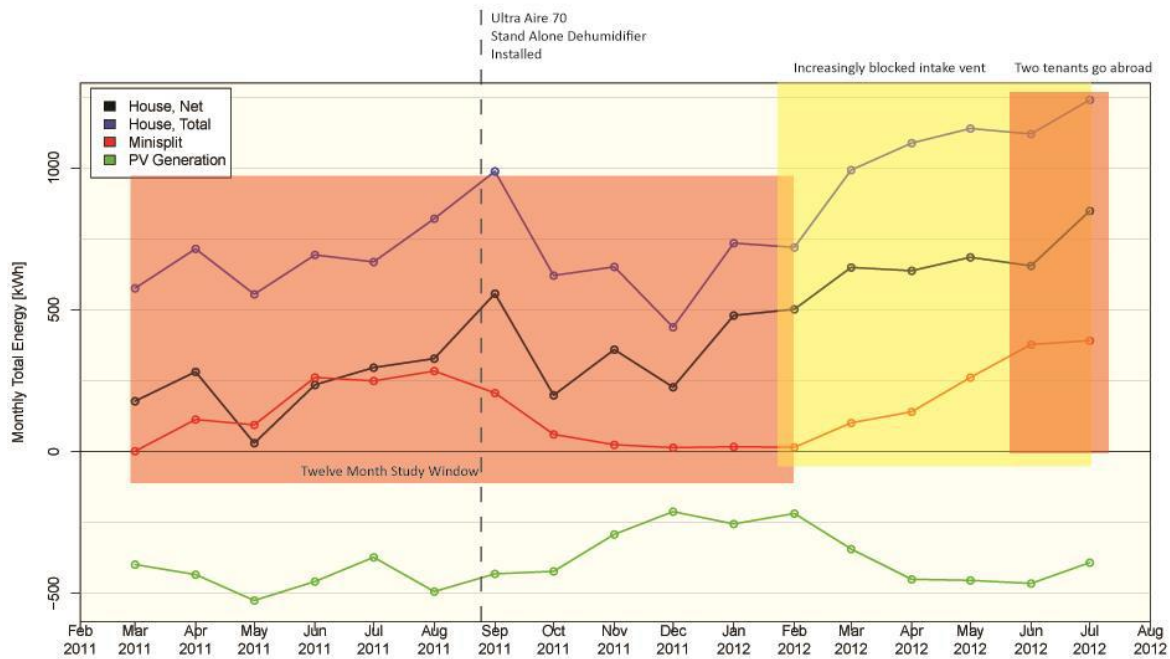


Figure 3-13 LeBois house's actual energy usage (White, 2014)

3.5.3 Office building in Al Khawaneej, Dubai, UAE

The UAE climate presents significant challenges for accomplishing low levels of energy demand in buildings because of the high air temperatures with regular high levels of solar radiation and humidity (Shanks and Nezamifar, 2013). The building sector in UAE is consuming 80 per cent of the UAE's energy, so the building sector has a key role to play when it comes to energy efficiency (Clarke, 2016). Also, up to 80% of building total electricity demand is used for cooling (Shanks and Nezamifar, 2013). To address this challenge, the governance in the UAE has been announcing a number of vision statements and measures to urge, encourage, and support the industry's multiple stakeholders to raise the bar on building performance (Fayyad and John, 2017).

Dubai's government, through the Mohammed bin Rashid Space Centre (MBRSC) in 2016, was planning to establish a laboratory specializing in conducting experiments and tests for sustainable autonomous houses to verify the efficiency of devices, systems and materials. MBRSC was developing an office building in Dubai (Figure 3-14) that was recognised as a pioneer to translate the theory of a Passivhaus in a very hot climate into practice. This project was the first project in extreme climatic conditions in the Arabic Area to acquire the certification by Passivhaus Institute (Passive House Database, 2016). The sustainable

autonomous building produces energy from the sun and was the first building model established to be self-sufficient and totally autonomous from the electricity grid.

The site location is within the city of Dubai, close to the existing MBRSC buildings. The building is composed by ground floor and first floor with a usable surface 410 m². From Figure 3-15 can be seen that the building walls that is facing east and west having almost no openings, wall that is facing north characterized by an added external volume serving as vestibule room and wall that is facing south view that recalls the concept of the inner court (Passivhaus Institute, 2016). The office building was designed as anti-solar design, that almost all the glazing concentrate in the inner court and was protected from direct sunlight by external wall and photovoltaic (PV) in the roof.



Figure 3-14 Dubai's MBRSC has revealed a fully sustainable autonomous house in the UAE (Dubai Government Media Office, 2016)

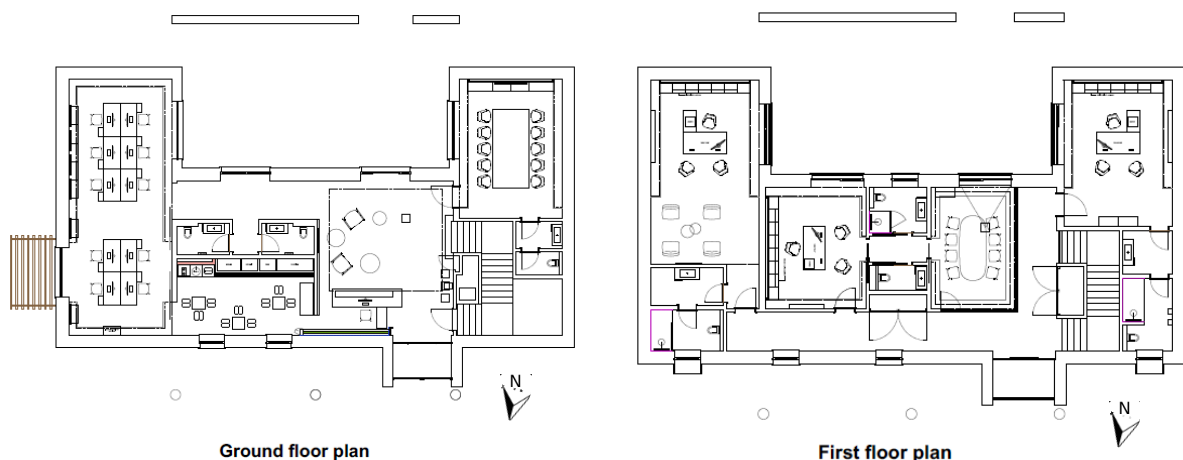


Figure 3-15 Office building floor plans (Passivhaus Institute, 2016)


Table 3-4 Building's data of Passivhaus office in Dubai (Passivhaus Institute, 2016)

Year of construction/ Baujahr	2016	Space heating / Heizwärmebedarf	0 kWh/(m ² a)
U-value external wall/ U-Wert Außenwand	0.076 W/(m ² K) 0.090 W/(m ² K)	Space cooling / Kühlbedarf	50 kWh/(m ² a)
U-value basement ceiling/ U-Wert Kellerdecke	0.108 W/(m ² K)	Primary Energy Renewable (PER) / Erneuerbare Primärenergie (PER)	73 kWh/(m ² a)
U-value roof/ U-Wert Dach	0.076 W/(m ² K)	Generation of renewable energy / Erzeugung erneuerb. Energie	185 kWh/(m ² a)
U-value window/ U-Wert Fenster	0.89 W/(m ² K)	Non-renewable Primary Energy (PE) / Nicht erneuerbare Primärenergie (PE)	143 kWh/(m ² a)
Heat recovery/ Wärmerückgewinnung	89 %	Pressure test n ₅₀ / Drucktest n ₅₀	0.48 h ⁻¹
Special features/ Besonderheiten	electric storage 25kWh, water recovery from condensation drain		

Table 3-4 describes the U-values of the building materials for the office building. The walls were prefabricated and were imported from Italy (Passivhaus Institute, 2016). With many of the wall connections made on site, the building pressure test was also used to check the building leakages. The final pressure test value was 0.48ach⁻¹, and this complied with the Passivhaus requirement. Figure 3-16 shows the verification sheet from this office building that indicate the building is fulfilled the Passivhaus criteria (Passivhaus Institute, 2016).

A total power of 40 kW, coupled with a 25kWh electrical storage, is provided by a PV field array composed of polycrystalline silicon modules installed in the building roof (Passivhaus Institute, 2016). Regardless of the massive amount of electricity production, the building became unsuccessful to meet Passivhaus Plus requirements due to the fact that the electrical storage is kept in an auxiliary building (Figure 3-17). In order to guarantee the batteries' stability, a separate air conditioning unit was installed to keep the room under 30°C and this air conditioning electricity consumption had to be accounted for in PHPP.

Passive House Verification

		Building: pilot project "Passive House in Dubai"	
		Street: Al Khawanej Street	
		Postcode/City: Al Khawanej	
		Province/Country: Dubai AE-Vereinigte Arabische Emirate	
Building type: office building		Climate data set: AE0001a-Dubai	
Climate zone: 7: Very hot		Altitude of location: 6 m	
Home owner / Client: MBRSC - Mohammed Bin Rashid Space Centre		Street: Al Khawanej Street	
Postcode/City: Al Khawanej		Province/Country: Dubai AE-Vereinigte Arabische Emirate	
Mechanical system: Energy Plus Project		Street: piazzetta San Marco, 7/8	
Postcode/City: 31053 Pieve di Soligo		Province/Country: Treviso IT-italien	
Certification:		Street:	
Postcode/City:		Province/Country:	
Year of construction: 2016		Interior temperature winter [°C]: 19,4	
No. of dwelling units: 1		Internal heat gains (IHG) heating case [W/m²]: 2,8	
No. of occupants: 16,0		Specific capacity [Wh/K per m² TFA]: 84	
		Interior temp. summer [°C]: 25,0	
		IHG cooling case [W/m²]: 2,8	
		Mechanical cooling: x	

Specific building characteristics with reference to the treated floor area				Criteria		Alternative criteria		Fulfilled? ²
Space heating	Treated floor area m²	410,8		15	-		yes	
	Heating demand kWh/(m²·a)	0	≤	-	-			
	Heating load W/m²	-	≤	-	-			
Space cooling	Cooling & dehum. demand kWh/(m²·a)	50	≤	19	57		yes	
	Cooling load W/m²	9,7	≤	-	10,7			
	Frequency of overheating (> 25 °C) %	-	≤	-	-		-	
	Frequency excessively high humidity (> 12 g/kg) %	0	≤	10	-		yes	
Airtightness	Pressurization test result n ₅₀ 1/h	0,48	≤	0,6	-		yes	
Non-renewable Primary Energy (PE)	PE demand kWh/(m²·a)	143	≤	-	-		-	
Primary Energy Renewable (PER)	PER demand kWh/(m²·a)	73	≤	60	73		yes	
	Generation of renewable energy kWh/(m²·a) (in relation to projected building)	185	≥	-	19			

² Empty field: Data missing; "-": No requirement

Figure 3-16 Excerpt from verification sheet in PHPP for Passivhaus in Dubai (Passivhaus Institute, 2016)

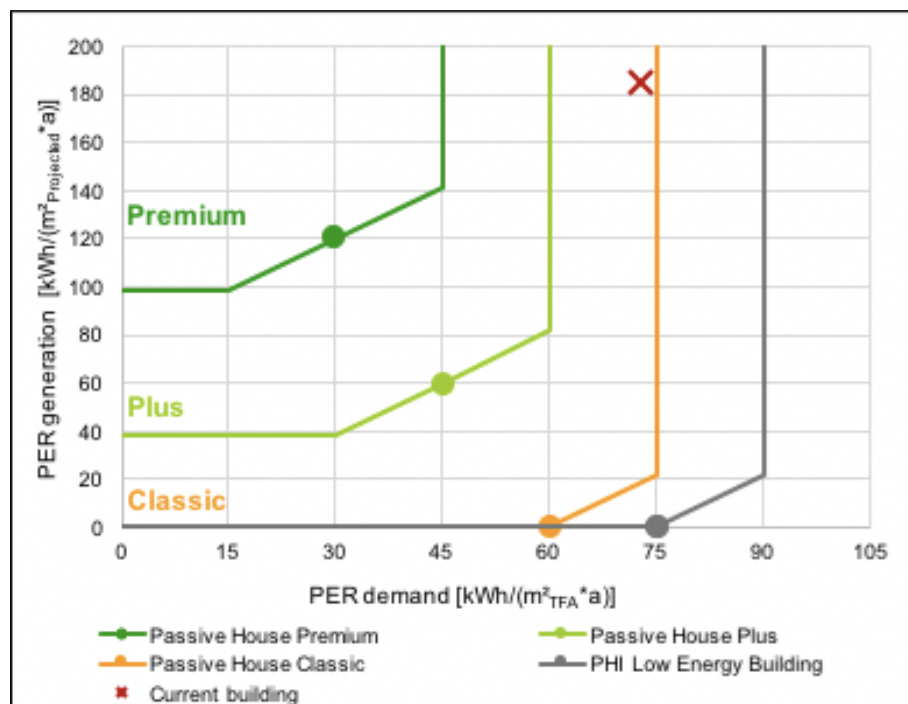


Figure 3-17 excerpt from PER sheet in PHPP for Passivhaus in Dubai (Passivhaus Institute, 2016)

With Dubai climate conditions, internal thermal masses cannot be passively unloaded. In opposing the building need to be actively kept under control in order to avoid supplements. The mechanical system is clearly concentrated on cooling (Passivhaus Institute, 2016). There are three different cooling systems that have been installed for research purposes, with the possibility to couple them to get the best results in terms of efficiency and comfort (Brumana et al., 2017).

- Supply air cooling or dehumidifying: Three HRVs with static sensible heat recovery that coupled with cooler and dehumidifier. Cool is generated by a water / water heat pump, with an external dry cooler. The chilled water's design flow temperature is 7 °C, to guarantees air condensation that cover latent load (being latent load often the higher portion of the total cooling load). Latent load is treated in air / water coils which are placed in the supply air ducts of the heat recovery ventilation (HRV) units. These coils are coupled with a second, hot water operated, coil in case pure dehumidification service is required.
- Recirculated air cooling: To face the high internal heat gains in consequence of building is functioned as an office, additional fan coils operating at 7 °C were installed to match the uncovered sensible load.
- Floor cooling: A radiant floor system was installed with a design flow temperature of 20 °C. Radiant floor is used to keep masses under control rather than a conventional cooling system, to allow for lower mean radiant temperature thus enhancing the thermal comfort.

A computer model was developed, aimed to predict the energy performance and the thermal comfort of the office building (Brumana et al., 2017). The simulation results (Table 3-5) demonstrate the strong influence of latent loads caused by high relative humidity levels to achieve the comfort level in the office building. With the actual cooling system that was modelled in the computer building model, the total cooling load from the simulation made was 82.24kWh/(m²a). This number is above the design cooling system that was predicted to be 50 kWh/(m²a) (Passivhaus Institute, 2016). But this number was far lower than typical office building in UAE. The cooling energy for offices in Abu Dhabi buildings annually was around 243.1 kWh/m²/year (Al Amoodi and Azar, 2018).

Table 3-5 Building cooling load of Passivhaus office in Dubai (Brumana et al., 2017).

Annual Load		
	unit	value
Air Load - sensible	kWh	7954.6
Air Load - latent	kWh	11920.7
Floor Load	kWh	13844.5
Total Load	kWh	33719.9
Total Load / Net Floor Area	kWh/m ²	82.24

3.6 Cooling and dehumidification in Passivhaus building

As the Passivhaus strategies require airtight buildings, efficient mechanical ventilation is essential as a suitable source of fresh air (Passipedia, 2015). Heat Recovery Ventilation or HRV, is an energy recovery and heat exchange, mechanical ventilation system that provides fresh air throughout a passive house. This method of ventilation dramatically improves climate control and air quality, whilst saving significant amounts of energy by reducing heating and cooling demands. The Passive-On study forecast a number of issues related to Passivhaus criteria for warmer climate, including the introduction of a limit for summer cooling energy demand, a higher infiltration rate and an indoor comfort temperature that coincided with adaptive thermal comfort standards (eERG, 2018). The application of the Passivhaus standard must also properly consider moisture balances and latent loads for buildings in a hot and humid climate.

The Passivhaus energy performance targets define the standard and must be met in order for certification to be achieved (Passive House Institute, 2016). In the updated requirement, that was published together with the launch of version 9 of the Passive House Planning Package (PHPP), clearly indicated that variable limit value for the dehumidification fraction subject to climate data (Table 3-1). Cooling and dehumidification are inseparable unity in Passivhaus building built with hot and humid climate.

From the three cases of Passivhaus in different climate that was described in section 3.5 can be seen that the heat exchangers that have been widely used in the Passivhaus building were used also in the Passivhaus building built in hot and humid climate. But in addition of this heat exchanger there are a few different cooling types was used. There is a floor cooling strategy that is used by the Austrian Embassy (Austrian Embassy Jakarta, 2019) and Dubai office building (Passivhaus Institute, 2016) and a 1-ton mini-split air-conditioning system that was

Applying the Passivhaus building standard can preserve stable interior temperatures, but in tropical climates with high temperature and high humidity, an airtight envelope might hinder the removal of excess moisture. With extreme air tightness and high R-values in Passivhaus construction, failure to properly consider moisture balances and the attendant latent loads on the Passivhaus building in hot and humid climates, can lead to discomfort or moisture-related problems such as mould (Walker and Sherman 2007). The house needs a means for active dehumidification for optimal control over the comfort zone. In Kansas City, houses with an HRV (and tighter construction) spend more time above 60% relative humidity than more leaky homes. In other words, passive house construction that used ERV has damped out external temperature swings but has not removed internal moisture generation. (O’Kelly, Walter, and Rowland 2014, p.216). Lowering the indoor air temperature will reduce the moisture capacity of the indoor air and can, despite removing more moisture, lead to increase relative humidity (O’Kelly, Walter, and Rowland 2014, p.217). However, as expected, lowering the cooling set point increases energy use.

3.7 Summary

The Passivhaus Institute (PHI), the Passivhaus organization, has indicated that the Passivhaus is not a brand name but a construction concept that can be applied by anyone and that has stood the test of practice. A Passivhaus, states that: *“A Passive House is a building in which thermal comfort can be guaranteed solely by heating or cooling of the supply air which is required for sufficient indoor air quality without using additional recirculated air”* (McLeod et al., 2013). The German Passivhaus standard success in the first Passivhaus projects, with very low energy consumption and high thermal comfort levels, stimulated the spread of the Passivhaus standard to other countries in Europe and beyond. Even though the initial developments were made within Central and Northern Europe, the findings suggested that the market for Passivhaus should not just be limited to Central Europe, and that the ultra-low energy standard could be a feasible option in different climates.

Three cases study of the Passivhaus building built in hot climate shows that the Passivhaus standard can be applied in different climate zones. The case studies’ building performance indicated that the energy demand of Passivhaus building was lower compared to typical buildings of the same type and in the same area, even though the calculated energy demand in PHPP software indicated a lower number than the actual energy demand. The Passivhaus

in hot climates stress that cooling and dehumidification are the key features to bring thermal comfort to the occupant.

While ERVs can help to solve some problems related to the amount of moisture within the building envelope they can only function as well as the conditions inside and outside the building allow. For example, if both the indoor air and outdoor air are too humid the ERV cannot bring either air stream back into specification. The house needs a means for active dehumidification for optimal control over the comfort zone. There are several innovative new dehumidification techniques that are currently being explored by researchers. One such technique is hybrid heat pump and solid desiccant systems, which are also known as separate sensible and latent cooling systems. These systems would be ideal because they provide excellent control of the latent load and they also reduce the energy consumption of the heat pump.

To analyse the impact of the Passivhaus standard in terrace housing located in the hot and humid climate of Indonesia, typical dwelling types in Indonesia need to be identified, and this will be discussed in the next chapter.

Chapter Four

4 DEVELOPING THE CASE STUDY

4.1 Overview

The Indonesian government continues to encourage the development of low energy and sustainable building in Indonesia (Hartati, 2017). The government body for the development of sustainable building (Kementerian Energi dan Sumber Daya Mineral) is actively pushing housing sector to source a sustainable solution on creating low energy building (ESDM-RI, 2018). The 'Penghargaan Soebroto' was made as an appreciation from the government to the building that able to reduce the energy consumption. With the building energy from housing sector is growing every year, the low energy housing will be an alternative to reduce the energy and will reduce the global impact of climate change. The institution of engineers Indonesia (PII) highlighted that the effective energy used are able to reduce negative impact to the environment, in particular if able to reduce the heat gain into the building will reduce the cooling energy (Prima, 2016).

One low energy building standard that has developed rapidly is the Passivhaus standard. Most Passivhaus buildings are located in cool to mild climates and currently there is no housing built in the Passivhaus concept in tropical countries (Passivhaus Institute, 2019). Building modelling has been used as an early lesson to support the way the buildings could be designed and constructed (Attia et al., 2012; Oduyemi and Okoroh, 2016). To explore the possibility of applying the Passivhaus standard in a hot and humid climate region, a building simulation was then used to be able to create the building model with applied Passivhaus standard and study the building performance under this climate. Creating the building model that is as close as possible to the real conditions is important to be able to make the study of the Passivhaus standard application into typical building built in tropical climates as close as possible to the real condition. In this research, the typical housing built in Jakarta Metropolitan Region were chosen as the case study house. The selected house will be monitored to gain more data to be used as source for validation process.

4.2 Indonesia's climate

Indonesia is located between 6°08' N–11°15' S and 94°45'–141°05' E. It is located on the Equator line, covering both sides of the Equator. According to the World Map of the Köppen-

Geiger climate classification, Indonesia is included in the Af category, that is equatorial rainforest with fully humid zone (Kottek et al., 2006). The climate is generally hot and humid, with only a small variation of temperature throughout the year. With this location, Indonesia has a tropical climate with two distinct seasons: monsoon wet and dry. The rainy season is typically from November to April, with some regional variations. Jakarta, the national capital, has the heaviest rainfall from January to February. Typical annual rainfall differs greatly with the lowlands getting about 1.7 to 3.1 cm and the mountainous regions receiving up to 6.1 cm.

Contrasting with the four-season countries in which ambient temperatures fluctuate significantly between the seasons, Indonesia, with its warm and humid tropical climate, has a similar ambient temperature between wet and dry seasons, throughout the year (Karyono, 2018). The temperature variations between dry and rainy seasons in most places in this country are very small. Normally, during the day, the outdoor air temperature is very high, and the temperature difference between day and night is also not too big (Case et al., 2007). The minimum average daily temperature is 23°C, the maximum daily average temperature is 33°C, the average relative humidity is between 69% and 90%, and the average wind velocity is between 0.2 and 0.8 m/s (Karyono, 2000).

According to the Minister of Health of Indonesia, a healthy home has a comfortable air temperature ranging from 18 to 30°C, and humidity ranging from 40 to 70% (Badan Pusat Statistik, 2013). Using air temperature as a unit of thermal measurement scale would be easier to use for anybody concerned, as it is easy to find the equipment used to measure it in any location, and it is quite common for people to use it (Karyono, 2015). The majority of the Indonesian people live in naturally ventilated houses; these hot and humid climatic conditions might have a considerable effect on the occupant's thermal comfort perception (Feriadi and Wong, 2004). Under a hot and humid tropical climate, people prefer cooler environment conditions. It would be intuitive to assume that humidity should play a dominant role in the human perception of thermal comfort and perceived air quality in hot and humid climates, particularly so in air-conditioned buildings (Sekhar, 2016).

4.3 Jakarta's Housing Stock

Jakarta is the capital of Indonesia; it acts as the center of government and a commercial center. To support the exponential growth of urbanization, surrounding areas of Jakarta have

become the extension of satellite cities for Jakarta. The Jakarta Metropolitan Region covers an area of approximately 7500 km², including Jakarta City and its surrounding areas of Bogor, Depok, Tangerang and Bekasi (Firman, 2004). The current development for housing products in the Jakarta Metropolitan Region is expanding horizontally to surrounding areas around Jakarta and is reaching parts of the neighboring provinces (Rahadi et al., 2015).

Table 4-1 shows the proportions of dwellings with different floor areas in the Jakarta Metropolitan Region (Badan Pusat Statistik, 2011). From the total of households in every province/ regency in the Jakarta Metropolitan Region (Figure 4-1), the most prevalent housing floor areas lie between 50m² to 69m² floor area, except for DKI Jakarta Province, where the biggest percentage is for housing under 20m². The low dwelling floor areas percentage in Jakarta was mostly because the calculations includes the apartment room and housing in slum areas, where the houses/unit's floor area were mostly below 20m² as the result of the limited land availability in capital city. With this information, can be concluded that the typical building built in Jakarta Metropolitan Region is dwelling with 50m² to 69m² floor area.

Table 4-1 Built dwelling units percentage floor area in the Jakarta Metropolitan Region (Badan Pusat Statistik, 2011).

Province/ Regency/ Municipality	Percentage Floor Area of Dwelling Unit (%)										Total
	<20m ²	20-29 m ²	30-39 m ²	40-49 m ²	50-69 m ²	70-99 m ²	100- 149 m ²	150- 199 m ²	200- 299 m ²	>300 m ²	
DKI Jakarta Province	27	12	13	7	11	10	9	4	4	3	100
Bogor Regency	7	11	16	15	23	17	8	2	1	0	100
Bogor	9	11	12	11	19	17	12	4	3	2	100
Depok	7	9	14	8	18	20	15	5	3	1	100
Tangerang Regency	11	11	13	14	27	16	5	1	1	0	100
Tangerang	19	12	12	6	17	17	11	3	2	1	100
Tangerang Selatan	6	9	14	8	20	18	15	5	4	2	100
Bekasi Regency	9	13	12	14	29	15	6	1	1	0	100
Bekasi	9	11	13	7	18	19	14	5	3	1	100
Source: 2010 Population Census Data - Statistics Indonesia											

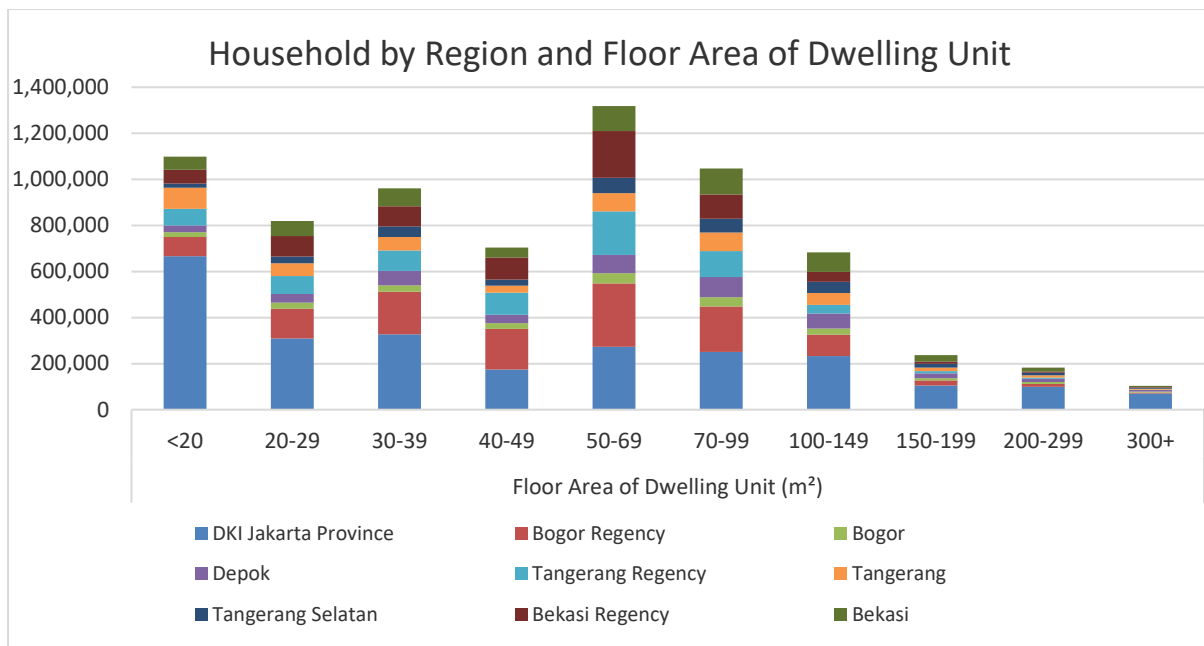


Figure 4-1 Household classification by Region and floor area of dwelling unit.

4.4 Description of case study dwelling

The analysis in the previous section indicated that the typical dwelling in the Jakarta Metropolitan Region has a floor area in the range of 50m² to 69m². The case study dwelling chosen was within this category. The selected case study location is in Cibubur Country in Depok region, which is a satellite city of Jakarta (Figure 4-2). Cibubur Country is one part of large housing development in Depok region. With the location just after the border of Jakarta administration line, housing built in this area is mainly to cover the housing shortage in capital city, since there is limited land availability in Jakarta. Subsequently, the housing in this area mainly occupied by people who work in Jakarta.

The housing in this development were built as a one floor row house, but there were a few owners that modified the houses become two floor or combining two houses become one. Figure 4-3 shows the images of selected row house representing the typical housing built in Jakarta Metropolitan region that was chosen as a case study. The house site area measured 6 m by 15 m with a building floor area of 55 m² and a floor-to-ceiling height of 2.85 m (Figure 4-4). The house has two bedrooms (master bedroom and kid bedroom), a living room that attached with kitchen area, bathroom, and service area. This row house is still in its original façade, but an additional flat roof was added above the kitchen area. The building was oriented towards north, which means that the external façade of the children's bedroom

faced north. The building window was mainly facing North, with one window (master bedroom) opening to the service area. Additional metal canopy was made above the carpark area, in front of the children's bedroom, that was used as protection for the car. The interior of the building can be seen in Figure 4-5. This house was using an air conditioning unit to cool the master bedroom and children's bedroom, whereas in the living room it was using a wall fan.

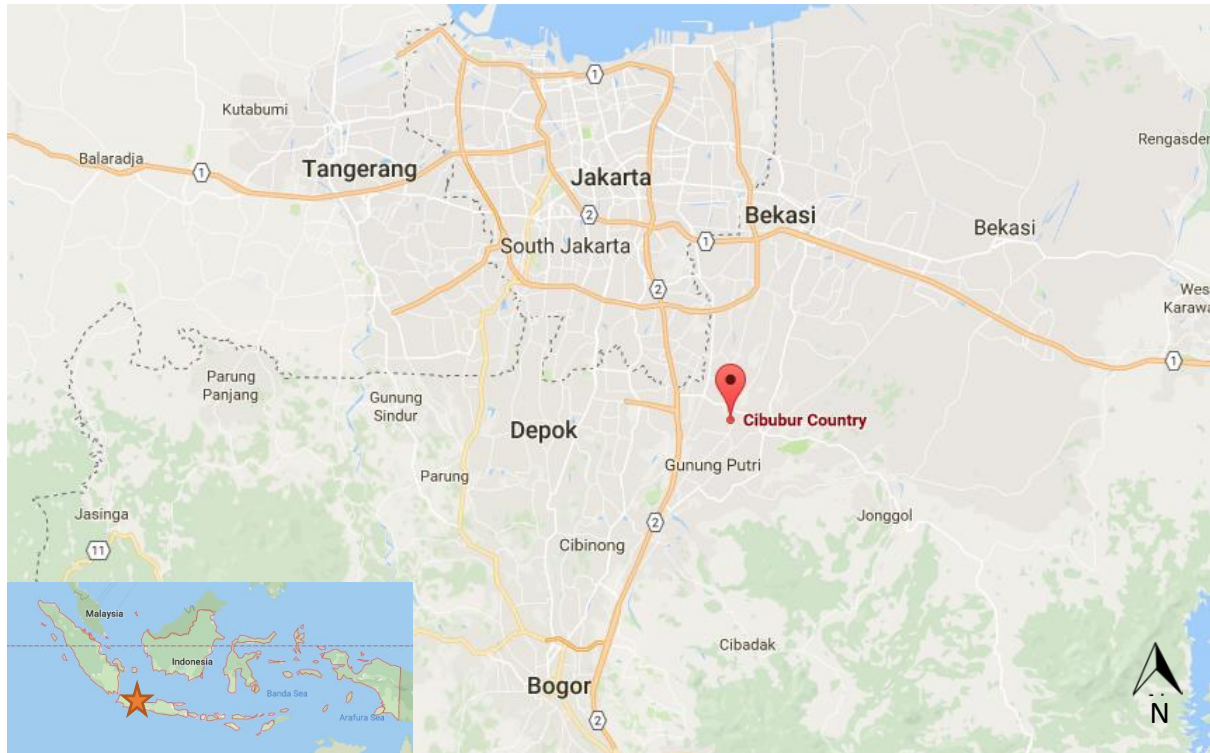


Figure 4-2 Case study location in relation with Jakarta Metropolitan region (Google, 2019)



Figure 4-3 The exterior view of case study row house

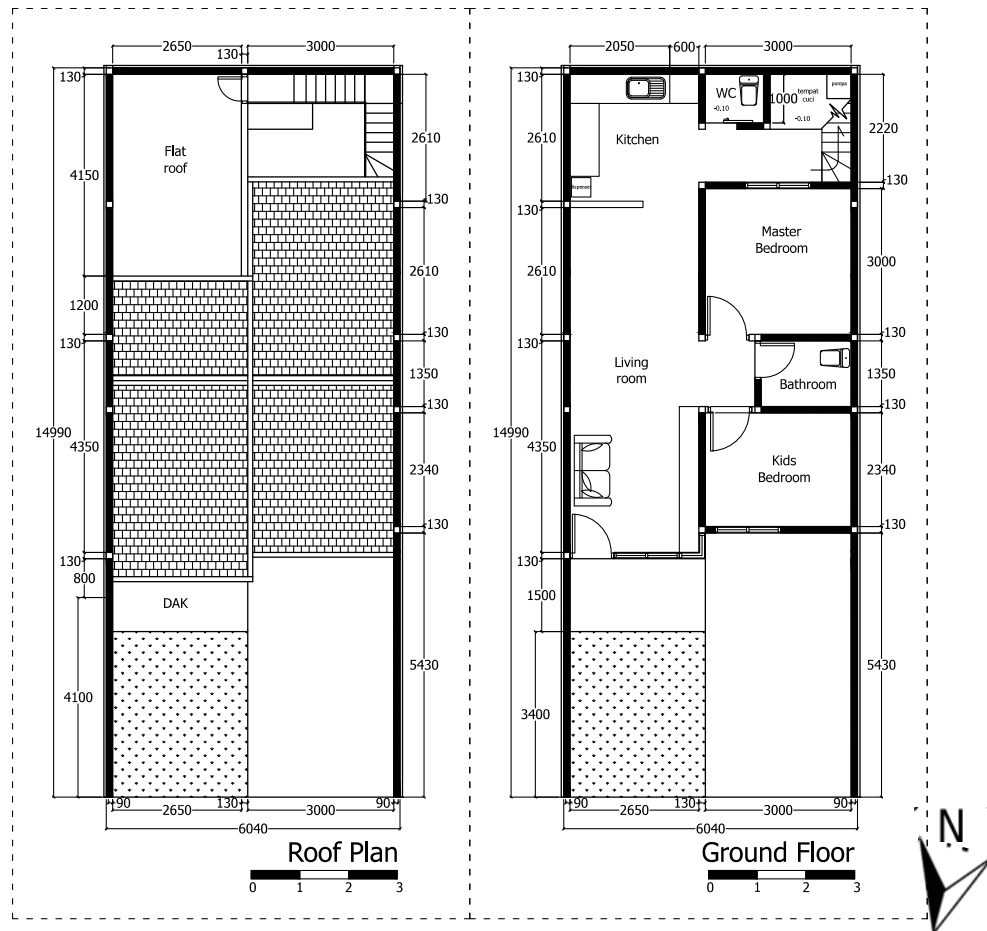


Figure 4-4 The floor plan of case study row house

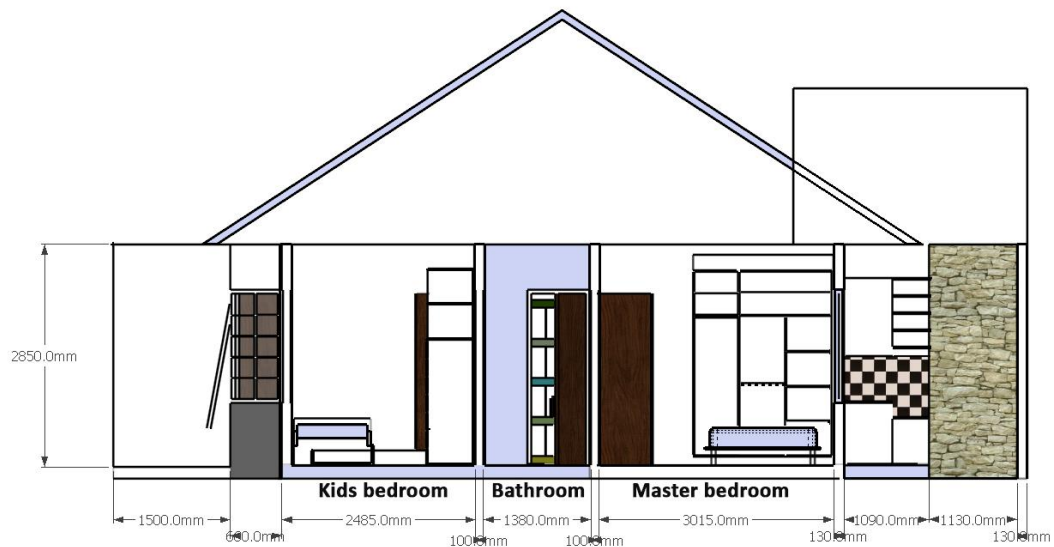


Figure 4-5 The section of the case study row house

4.5 Building Fabric

The selected case study house is a single brick construction (Figure 4-6). The common practice in the housing construction sector in Indonesia that the entire building is built without insulation, being constructed from a single layer of brick, with single glazing windows (Eka et al., 2018; Sakina, 2020; Utama and Gheewala, 2008). The case study dwelling is using the commonly used building materials in the country. The house's walls are made of bricks with the floor material was dominated by ceramic tiles, the roof material are roof tiles and the ceiling material is gypsum board. The windows are using clear single glass with awning on the internal side which gives more privacy to the residences. Construction materials used for the case study dwelling are listed in Table 4-2.

Table 4-2 Original building elements.

Building Element	Constructional layers
External and internal walls	25 mm thick cement plaster + 100 mm thick clay brick + 25 mm thick cement plaster
Party wall	25 mm thick cement plaster + 200 mm thick clay brick + 25 mm thick cement plaster
Floor	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + soil layer
Window	6 mm thick single layer clear glass
Ceiling	6 mm thick gypsum board
Pitched roof	20 mm thick roof tile + 25 mm thick timber batten
Flat roof	22 mm thick cement screed + 100 mm thick concrete slab + 20 mm thick cement plaster

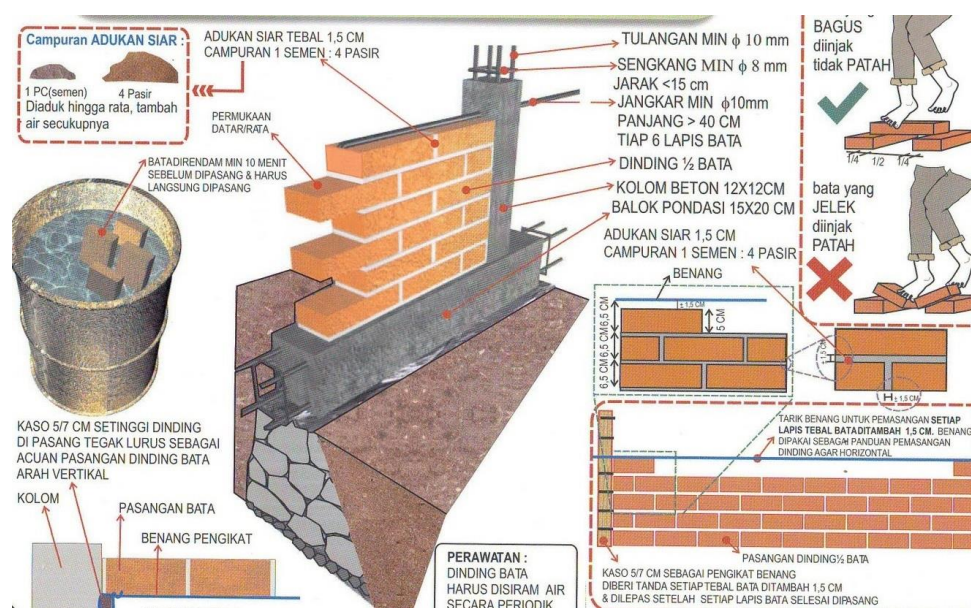


Figure 4-6 Typical single brick construction detail in Indonesia (Ramadhan, 2019)

4.6 Occupancy schedules and profiles

The monitored house was occupied by a couple and their three children. On the working days from Monday to Friday, the husband was working in Jakarta, the capital city of Indonesia, and the two children were going to school nearby, so the house was mainly occupied by the mother and a baby during the day. During the monitoring process in the case study house, the occupant activity was recorded. From the monitoring process, it could be seen that, generally, the activity in the house during weekdays was typical for every week. There were only slight differences, such as the visit from neighbour, extended family or friends, which sometimes occurred only for a few minutes or hours. Activity during the weekends were mostly irregular, with sometime the whole family staying in for the whole day at home but on another weekend the family would leave the house empty for the whole weekend.

During weekdays, the husband and two children were mainly at work or school. The two children were back from school in the afternoon at 12.00 and 14.30 and would stay with the wife and baby until the next morning. The main activity areas for the children were not just limited to the living room, but also the master bedroom, living room and kitchen area. Sometimes the children were also playing in the front yard. The master bedroom and childrens' bedroom doors were mainly open during the day. The baby had a nap time for an hour or more between 12.00 – 14.30, and all children and the baby would prepare for bedtime at 18.30. During the monitoring process, the children were still sleeping with their parents. So, the master bedroom air-conditioning unit was switched on during the nap time for 20 – 30 minutes, and during sleep time from 18.30 – 05.00. The occupant schedule during weekday can be seen in Table 4-3.

Table 4-3 Occupancy schedules on the weekdays (Monday to Friday)

Time	Husband	Wife and baby	Child 1	Child 2	Note
00.00 – 05.00	√	√	√	√	Children were asleep
05.00 – 08.00	√	√	√	√	
08.00 – 12.00	-	√	-	-	
12.00 – 14.30	-	√	√	-	Baby sleep in the bedroom
14.30 – 18.30	-	√	√	√	Children were play
18.30 – 22.30	-	√	√	√	Children were sleep
22.30 – 00.00	√	√	√	√	Children were sleep

4.7 On-site Measurements

The monitoring of the selected row house was done in two selected periods, one in 27th January 2017 – 2nd February 2017 to represents the rainy season and the other one in 18th August 2017 – 5th November 2017 to represent the dry season. There were two parameters that were monitored, that is air temperature and relative humidity. Monitoring of these parameters was undertaken by using loggers that were placed in the two main activity in the house that is the master bedroom (Figure 4-7) and the living room + kitchen area (Figure 4-8). One logger used to monitor outdoor area was placed right outside the main door (Figure 4-9). The logger was located at 1.5m - 1.8m from the ground. The logger that was used in the January to February monitoring were Tinytag loggers, and the logger for the September to November monitoring was Rotronic data logger. The different types of logger used was because of equipment availability at the different times.



Figure 4-7 Master bedroom Logger location.

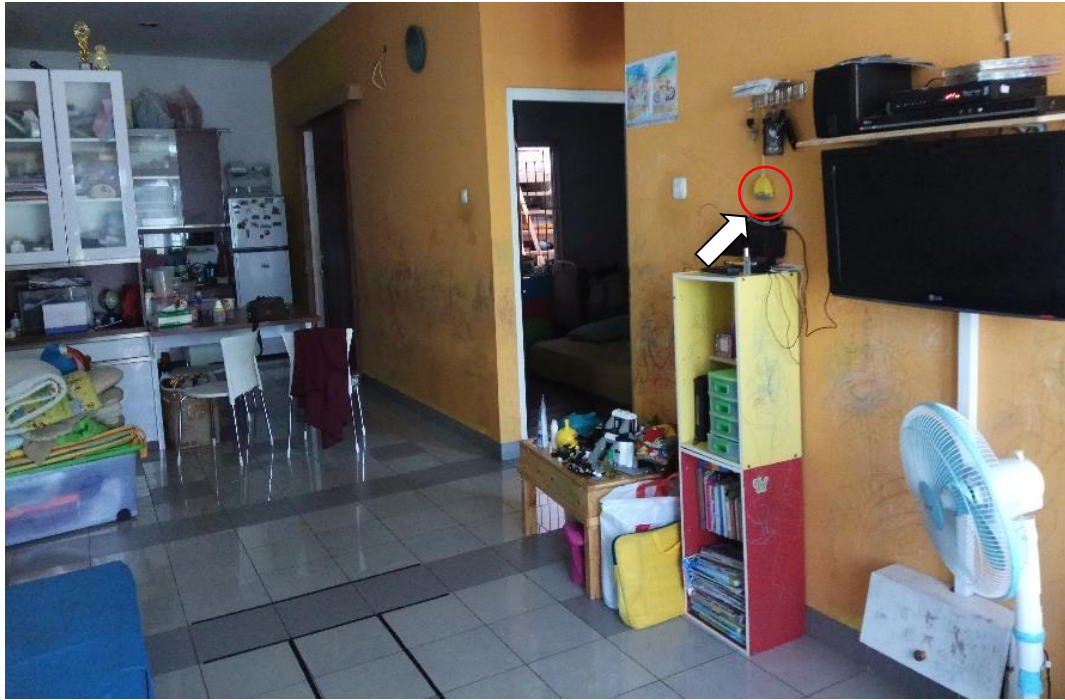


Figure 4-8 Living room logger location.



Figure 4-9 External logger location.

4.8 Data logger specification

There were two types of loggers used in this monitoring process - Tinytag data loggers and Rotronic data loggers. Loggers were used to measure the air temperature and relative humidity of the selected terrace house within the selected period.

4.8.1 Tinytag data logger

There were two different Tinytag logger types used in this measurement - for indoor Tinytag Plus was used and for outdoors a Tinytag Ultra was used (Figure 4-10). Both Tinytag data loggers have a high reading accuracy and resolution, large memories, a fast offload speed and a low battery monitor (Gemini Data Loggers, 2019). The loggers were able to record up to 32,000 reading and has splash-proof case for Tinytag Plus & waterproof case for Tinytag Ultra. Tinytag data loggers operates a Business Management System which follows to ISO 9001 and ISO 14001. The data logger's temperature reading range is -40°C to $+85^{\circ}\text{C}$, sensor type is a 10K NTC thermistor (Internally mounted), response time is 25 mins to 90% FSD in moving air, accuracy is better than $\pm 0.5^{\circ}\text{C}$ and the reading resolution is 0.01°C or better.

For relative humidity, the reading range is 0% to 95% RH using a capacitive sensor type, an accuracy $\pm 3.0\%$ RH at 25°C , a reading resolution better than 0.3% RH and 10 seconds to 90% FSD response time.



Figure 4-10 Tinytag logger a) Tinytag Ultra for indoor and b) Tinytag Plus for outdoor (Gemini Data Loggers, 2019).

4.8.2 Rotronic data loggers

The second data logger used in this measurement was from Rotronic (Figure 4-11). This data logger has a high measurement accuracy that is $\pm 3.0\%$ RH for relative humidity and $\pm 0.3^{\circ}\text{C}$ for air temperature (Rotronic, 2019). The measurement range was 0-100% for relative humidity, and -30°C - 70°C for the air temperature. The storage capacity is 32,000 reading that will be

full after 3 years with 60 minutes interval readings. The logger is set by HW4 software that is able to program the start and stop time. The reading is also readable through clear LCD with visual alerts.

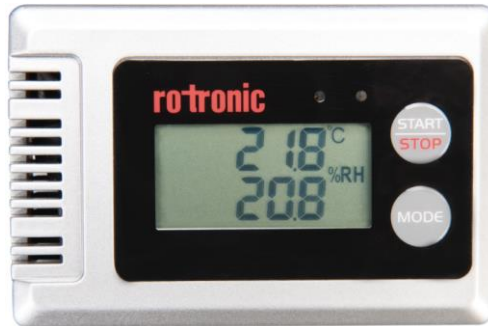


Figure 4-11 Rotronic data logger for indoor.

Chapter Five

5 ASSESSMENT TOOLS AND METHODS

5.1 Overview

This section explains some of the key concepts behind the modelling software used in this simulation. It is important to understand the capability and limitations of the software. As building design has developed into more complex forms along with more complex technologies, there has been a change in attempts to simulate and model the dynamics of energy flows in buildings (Andarini, 2010). Building simulation is now a key tool for making important design decisions at all stages of the construction process, and of particular importance in 'high-performance' building design (Reeves et al., 2012).

Building simulation nowadays can consider detailed occupancy schedules and internal gains patterns, high-resolution weather data, and heat stored thermal mass (Padovani et al., 2011). The additional dynamic calculations are giving crucial understanding into the thermal response & behavior of buildings. The weakness to this reality that the high level of inputs called for can contain assumptions which do not echo reality.

Building model validation is used to bring the simulation results as close as possible with the real condition (Gucyeter, 2018). By using building information such as building materials, cooling systems, lights and appliances, and a presupposed occupancy schedule from the case study house, a building model for computer simulation was made. The empirical validation of the model assembled in the software was determined by comparing the computer simulation results with field experiment data from the case study house. It should be clarified here that modeling refers to the task of making a logic machine that represents the material properties of the building and physics processes in it, whereas simulation refers to numerical experimentation with the model to investigate its response to changing conditions inside and outside the building.

5.2 Assessment Framework

This research was studying and analyzing the impact of applied the Passivhaus concept in a typical dwelling within a tropical climate, and to study the feasibility of applying Passivhaus concept with hot and humid tropical climate. The research was started with selecting the typical housing that built in Jakarta Metropolitan Region, that was later was made this

selected house as a case study. The next process was recording the air temperature and relative humidity in the case study house during the selected period. The case study was also replicate in the building simulation tool to build the building model and later on run the simulation under the tropical climate to study the building performance. However, in the beginning of the research project there was a difficulty on finding the housing that is suit the criteria as a ‘typical housing’ in Jakarta.

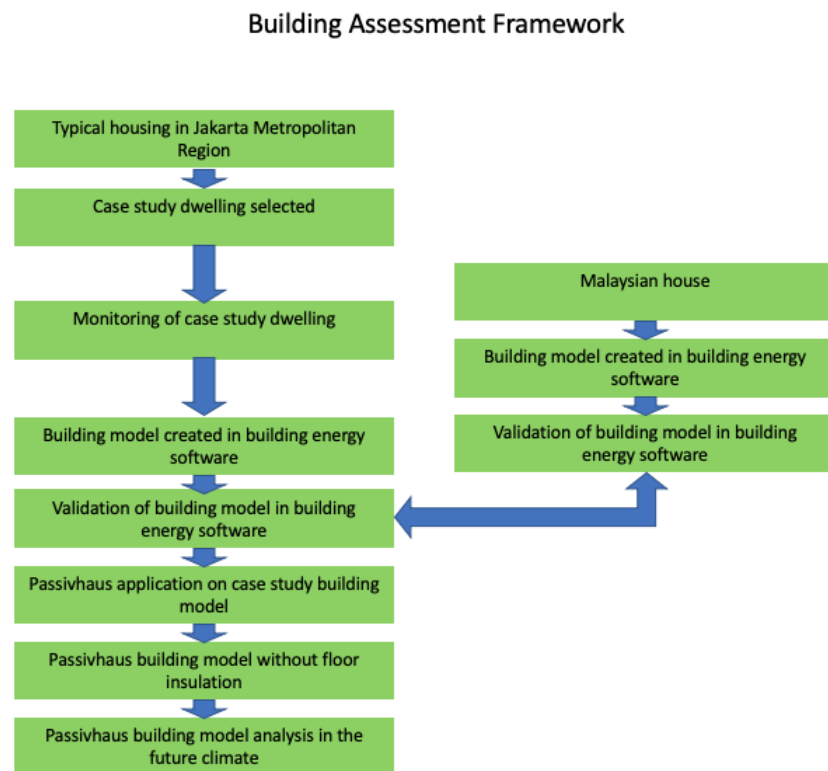


Figure 5-1 Assessment framework diagram.

While searching for the case study dwelling, in parallel, an analysis was started by choosing housing that had a similar climatic situation with Jakarta. A house in Johor Bahru in Malaysia was chosen because the house location was in the same climatic conditions as Jakarta, that is near the Equator line. This Johor Bahru house also had necessary measurement data that could be used to develop a building model in DesignBuilder software. In the process, this analysis had an important part as a learning process to understand the steps in creating the building model, simulate the building model, and analyze the building performance in DesignBuilder software. Through the analysis of Johor Bahru building model in the DesignBuilder, the building material was studied and validated. The building material

information from this validated building model was then used to create the building model of the case study house.

After the case study house was selected, and the air temperature and relative humidity measurements were done, the next process was to model the case study building in the building simulation software. The building information gained from the owner was used to create the building model. The air temperature and relative humidity data that was gained from data logger placed in the case study house, was used to validate the building model built in the simulation software. Back and forward processing were done by analyzing and comparing the actual measurements towards the simulation result to find the setting that should be used in the building model built in the simulation software. This process is carried out to produce a validated building model that can perform as close as possible with the real house built in hot and humid climate.

The validated house was then used as the basis for the next step, which is to study the performance of the Passivhaus standard in the dwelling built in hot and humid climate. The Passivhaus model was built in the building simulation tools to predict the energy use and to study if the thermal comfort levels are achievable. A number of scenarios were performed using a building performance simulation tool to evaluate the effects of Passivhaus application into the tropical housing, to learn the Passivhaus concept adaptation that should be used to be able to apply this concept in the housing built with hot and humid climate.

5.3 Building Simulation Tools

As the world is heading towards an energy conscious and efficient era, Building Performance Simulation (BPS) tools have become an essential and integral tool during the design of buildings (Nadarajan and Kirubakaran, 2016). BPS tools aid decision makers, designers, and engineers to understand the projected performance and expenses related to any project. Thermal comfort, energy performance, CO₂ emissions, energy costs, energy assessments and building life cycle are some examples of measurements obtained from BPS tools.

There are around 400 BPS tool available, making the selection process an overwhelming task for architects and engineers (Attia et al., 2012). While the selection may be the first difficulty that architects face, other challenges are related to the capability of the architects and

engineers to effectively use the tool itself. BPS tools are complex systems that require training and accuracy in the input data in order to get close to real results.

It is difficult to compare BPS's in absolute ways, because each BPS has its advantages and disadvantages. The choice of BPS tools should be made with carefully assessing the requirements of the user and to match the requirement with the capabilities of the BPS. Based on the research by Hong et al., there are three vital factors to consider the BPS from the user's side (Hong et al., 2000). The first is the user should be able to choose the appropriate software to solve the problem. An 'overpowered' BPS is expensive and can be costly when mistakes are made due to the complexity of the software. The second is relating to budget on purchasing and using a BPS includes software cost, maintenance (if needed), and the cost of the computer platform to run the BPS. In addition, provision should be made for user training. The third is the availability of the facilities, such as whether the existing computer facilities capable in running the tool and the anticipation of investment in new computer resource are affordable.

Commonly, BPSs can be assessed on their cost and performance (Hong et al., 2000). Computer software cost includes not only the purchase cost but also the use cost. The cost components include:

1. A software cost, covering the license fee, after sales service, and software upgrading fee;
2. A training cost, which is the fee that software vendors charge to train the user to use the software;
3. A use cost, which includes the labour and computer resources consumed during the use of a BPS, especially when a BPS requires a user to spend long hours preparing the input data files and waiting for simulation results.

During the initial phase of this research a decision had to be made in regard to the selection of the BPS tool, and the choice came down to two BPS tools. The first was DesignBuilder, which was the most commonly BPS tool used in UK (Jentsch et al., 2008) and amongst researchers in the University of Liverpool, with the license is available every year in the university. The basic tutorial on using DesignBuilder is also available in the University. DesignBuilder is coupled with the software tool EnergyPlus, which is great for

modelling three-dimensionally building geometry as well as a tool for building energy performance assessment (Andarini et al., 2009; Fokaides et al., 2016; Maile et al., 2007). The CAD links into the 3D modeler as well as report generation facilities are available. Therefore, the building may be visualized in 3D to support assessment of design. DesignBuilder combines rapid building modelling with up-to-date dynamic energy simulation and a wide range of templates, such as locations as well as their weather data, buildings model, construction materials, schedules, HVAC systems and lighting systems.

The second software is the Integrated Environmental Solutions – Virtual Environment (IES-VE) software, that provided a student version of the software that has lower price but the same complete software package. The IES-VE was used when there was a need to study the dehumidification effects on the building model. IES-VE is a software package generated by Integrated Environmental Solutions that is used for building sustainable design and energy analysis (Bhikhoo et al., 2017). To facilitate the simplicity of modelling and examining the building performance, the IES-VE provide a range of built-in analysis tools. Based on the initial comparison process, IES-VE was chosen because the software has a friendly graphical interface and appeared to be a comprehensive environmental set that would deliver a further continued learning curve. Online training, forums and face-to-face training were effortlessly achievable, making the learning process less overwhelming. Many online tutorials are available free or on a purchase basis, with some tutorials available on demand. For the purpose of this study the ease of the interface and geometry building, the speed with which results can be produced and the scale of the models needed to be simulated makes it ideal.

Since the research was analyzing the Passivhaus standard application in a typical dwelling built in a hot and humid climate, the Passive House Planning Package (PHPP) software was then used in this research to analyze the Passivhaus application into the building model.

5.3.1 DesignBuilder

The first software that was used was DesignBuilder, which was the most commonly used building simulation tool amongst researchers in the University of Liverpool. DesignBuilder software is with a more user-friendly version of the software tool EnergyPlus. DesignBuilder software is powerful for modelling three-dimensionally building geometry and at the same time can be functioned as a tool for building energy performance assessment. The software provides the link from CAD into the 3D modeler as well as report generation facilities. Hence,

the building may be visualized in 3D to support the building design assessment. DesignBuilder combines rapid building modelling with high-tech dynamic energy simulation. A wide range of templates is provided, such as locations with their weather data, some buildings model, construction materials, schedules, HVAC systems and lighting systems (DesignBuilder, 2019).

The DesignBuilder capabilities are:

- The ability to show a comprehensive range of simulation data in annual, monthly, daily, hourly or sub hourly intervals.
- Able to produce energy consumption that is broken down by fuel and end-use;
- Considering the heat transmission through building fabric including walls, roofs, infiltration, ventilation, and others.
- Calculating heating and cooling loads as well as CO₂ generation.
- Parametric analysis screens in DesignBuilder is also allow the user to investigate the effect of variations in design parameters on a range of performance criteria.
- In the recent release, the DesignBuilder is capable to use CFD integrated with the simulation model.

5.3.2 IES VE

The other software choice was Integrated Environmental Solutions - Virtual Environment (IES VE). IES VE is the key thermal engine used for simulations in this thesis. IES VE software has a graphical interface that is user-friendly and has a comprehensive environmental support that provide a further sustained learning curve. Online training, forums and face-to-face training were available, to support the learning process to become less overwhelming.

The thermal component of the IES VE toolkit, Apache, is a group of component modules that form the foundation for most simulations inside IES VE. ApacheSim is a dynamic thermal simulation tool, using mathematical principles to determine the heat transfer processes in and around a building. The template on the ApacheHVAC that was user-friendly was the main reason to use this software to make an analysis for Passivhaus application for typical building in Jakarta. The availability of a dehumidifier HVAC template in ApacheHVAC was able to accelerate the research process when studying the dehumidification process.

The program achieves Dynamic Simulation Model accreditation required by UK Building Regulations (IES VE, 2019). IES VE has been validated and tested against a number of

standards, such as ASHRAE 140, USGBC and BEST TEST. The inputs required in IES are (Harish and Kumar, 2016):

- a project compatible weather file, typically hourly,
- the geometrical configuration of the building and the building orientation,
- the building's construction data and thermophysical properties,
- HVAC system input,
- Occupancy schedule and household operational schedules.

The core engine was established in the 1980s as ESP-r software, managed by Clarke in the ABACUS group at Strathclyde University. IES VE was a commercial spin-out from the university, led by McLean (ESRU, 2019). The software confronted a battle after a 'fragile' issue in 1994, and by 2004 the company had developed to become a leader in the building modelling field in UK and in Europe. IES VE is widely recognized as the leading building analytics platform for top architects, engineers, and contractors, with customers including AECOM, Arup, Atkins, BDP, BuroHappold, Foster+Partners, Gensler, Ramboll, and WSP.

5.3.3 PHPP

Passive House Planning Package (PHPP) is the software developed by the Passivhaus Institute (PHI) to support the design of Passivhaus buildings, both domestic and non-domestic. The tool itself is all constructed in an Excel spreadsheet, with different worksheets containing the respective inputs and calculations for various areas. Planners need to complete PHPP for PHI or other local body certified by PHI, to be able to certify the end-product.

The main results provided by this software programme include (Passipedia, 2019):

- The annual heating demand [$\text{kWh}/(\text{m}^2\text{a})$] and maximum heating load [W/m^2]
- Summer thermal comfort with active cooling: annual cooling demand [$\text{kWh}/(\text{m}^2\text{a})$] and maximum cooling load [W/m^2]
- Summer thermal comfort with passive cooling: frequency of overheating events [%]
- Annual primary energy demand for the whole building [$\text{kWh}/(\text{m}^2\text{a})$].

Typical monthly climatic situations for the building site are chosen as the primary boundary conditions (particularly temperature and solar radiation). Based on this, the PHPP calculates

a monthly heating or cooling demand for the entered building. The PHPP can thus be used for different climatic regions around the world.

All the calculations in PHPP are based strictly on the laws of physics that are sourced from current international standards. Generalizations are essential in some locations and sometimes approximations may also be necessary, while for some areas there are no internationally relevant standards (Passipedia, 2019). This approach has resulted in an internationally reliable calculation tool with which the efficiency of a construction project can be assessed more precisely than with conservative calculation methods.

5.4 Weather data sets

Building simulation tools require weather data sets to complete the building performance analysis for the precise location of any project (Crawley et al., 1999). Some building simulation tools require hourly weather data sets, others require monthly weather data sets. Weather files explicitly represent the climate of the nominated location and generally include variables such as dry bulb and wet bulb air temperatures, relative humidity, solar radiation, wind speed, wind direction and cloud cover etc. for each hour of the year (EnergyPlus, 2019). The most frequently used weather file formats are the EnergyPlus Weather file format (EPW) and the Typical Meteorological Year (TMY2).

Weather files can be easily downloaded online through several websites, such as the Energy Plus website, for a vast number of locations. But for some specific locations weather data are not readily available, but weather files can be produced through numerous commercially available weather generator tools, such as Meteonorm. Meteonorm is a complete meteorological reference weather generator tool that offers several weather data formats for nearly any location around the world. Meteonorm uses data obtainable from weather stations for the designated locations by stochastically generating typical years from interpolated long-term monthly means (Meteotest, 2019). The hourly weather files accessible through websites are historical weather files sets which present weather data based on hourly climate observations for a number of years in the past (Crawley et al., 1999).

Jakarta's weather files, however, were not readily available on either the Energy Plus website or the built-in IES-VE weather files. For the validation purpose, the weather data recorded by the logger placed in front of the house during site measurements was used. The weather data

from the site measurements were used to make the building model situation as close as possible with the case study dwelling. The logger recorded the air temperature and relative humidity for the outdoor area from 27th January 2017 – 2nd February 2017 and 18th August 2017 – 5th November 2017. Meanwhile, for building model analysis, the weather data from Meteonorm was used to make a complete yearly analysis. Meteonorm was therefore used to acquire a present-day weather file in EPW format (Meteotest, 2019). The weather data that were used to analyze the future building scenario were also produced from the Meteonorm software.

5.5 Thermal comfort

The importance of indoor thermal comfort assessment and measurement is not only related to thermal satisfaction achievement; it is also to control energy usage and enhance indoor air quality (Nicol and Humphreys, 2002). Table 5-1 shows three main categories that affect thermal comfort in any given space: environmental, personal and other contributing factors (Szokolay, 2014).

The ASHRAE Adaptive Comfort Standard (ACS) model was developed from a global database that separated buildings into those that had mechanical system and naturally ventilated buildings (NV) (de Dear and Brager, 2002). Thermal comfort standards recognize that comfort depends on context. People living with air-conditioned spaces expect homogeneity and cool temperatures, while people who live in naturally ventilated buildings are used to thermal diversity. Their thermal perceptions are likely to extend over a wider range of temperatures than are currently reflected in the old ASHRAE Standard 55 comfort zone. The results of this adaptive comfort standard (ACS) are shown in Figure 5-2.

The important finding on the ASHRAE adaptive comfort standard study was the difficulty of creating generalization for areas that have mean outdoor temperatures above 23°C (de Dear and Brager, 2002). Above mean outdoor temperatures of 23°C, interior temperatures often rose beyond the ACS limits, with mean indoor operative temperatures grouped around 30°C, while based on the ACS, the neutral temperatures were calculated to be in the range of 26°C – 27°C. The research indicated that buildings in this zone are unable to maintain thermal comfort, even as defined by the ACS model, for many hours of the day. These uncomfortable buildings came from various regions of Pakistan, Australia, Greece, Singapore, Indonesia, and

Thailand. This is consistent with the research by Karyono, who found that there are some climatic differences between cities in the lowland and highland in Indonesia, which could lead to the difference on the people's comfort temperature due to physical adaptation (Karyono, 2018).

Table 5-1 Factors affecting thermal comfort (Szokolay, 2014).

Environmental	Personal	Contributing Factors
Air temperature	Metabolic Rate	Food and drink
Air movement	Clothing	Body shape
Humidity	State of health	Sub cutaneous fat
Radiation	Acclimatization	Age and gender

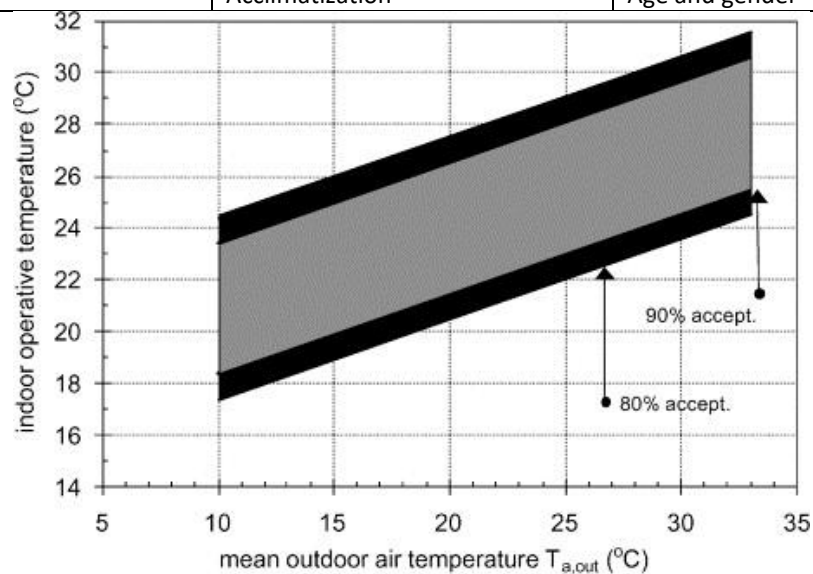


Figure 5-2 Proposed adaptive comfort standard (ACS) for ASHRAE Standard 55, applicable for naturally ventilated buildings (de Dear and Brager, 2002).

The effect of air movement and humidity are particularly important in hot and humid climates where the heat lost by evaporation predominates (Nicol, 2004). The Indonesian Standardization Board (BSN) specifies the comfort temperature for internal areas with maximum outdoor dry bulb temperatures of 28°C to 34°C is between 25.5°C ± 1.5 °C (Badan Standardisasi Nasional, 2011). This standard state a single comfort temperature should be applied in any building throughout the whole country. This standard disregard some results of earlier comfort studies in Indonesia, which indicated that people living in the big cities were comfortable at higher temperatures. The result from researchers who had researched on the comfort temperature for people in Depok area (Jakarta satellite town) indicate that the comfort temperature is slightly higher than the national standard, which is 27.5°C (Santy et al., 2016).

The Passivhaus standard was also require the internal temperature to be 25⁰C as described in the Passivhaus criteria and made in PHPP setting. These lower temperatures by BSN and the Passivhaus standard could lead to a higher cooling energy in the building and create an uncomfortable indoor environment. A more suitable standard or a guideline for Indonesian comfort temperature will help any air conditioning building to minimize its cooling energy. A regression equation of predicted comfort temperature (PCT) on the mean daily outdoor temperature that was studied by Karyono (Karyono, 2015) was:

$$\text{PCT} = 0.749 T_d + 5.953$$

Equation 5-1

PCT is the predicted comfort temperature and T_d is the average daily outdoor temperature.

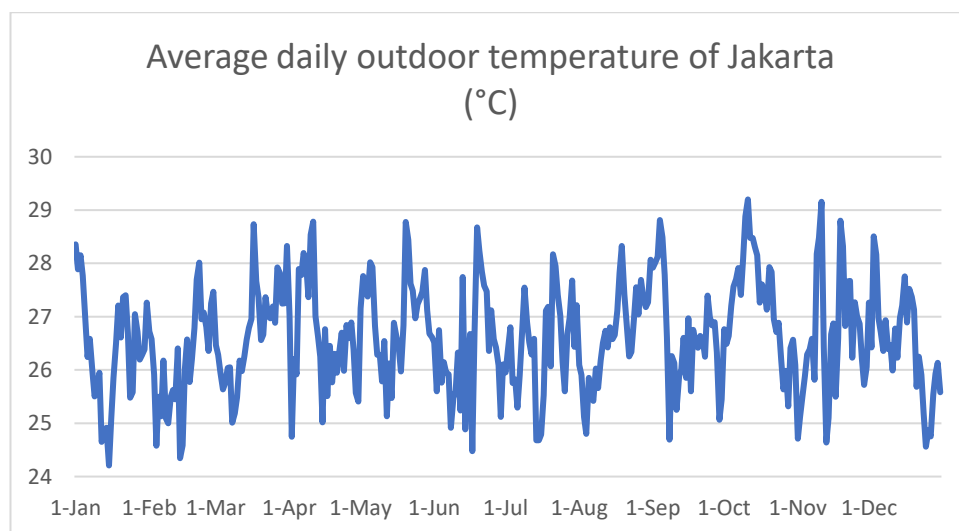


Figure 5-3 Average daily Jakarta's outdoor temperature of the outdoor dry bulb temperature generated from Meteonorm.

By using Equation 5-1 and the average daily outdoor temperature from Figure 5-3 it can be concluded that the comfort level will be in the range of 24⁰C – 27.8⁰C, which was used throughout this research as a thermal comfort range in Jakarta. The comfort relative humidity range is 30% - 65%, that is in line with ASHRAE standard (Bhattacharyya and Saha, 2014; Szokolay, 2014).

Chapter Six

6 VALIDATION OF BUILDING MODEL

6.1 Overview

In this chapter a three-dimensional dwelling model has been developed and analyzed using a computer program and comparing the simulation results with the house field measurement data. The modeling described here refers to the assignment of making a logic machine that symbolizes the material properties of the building and physics processes in it, where simulation refers to model numerical experimentation to investigate its response to varying conditions inside and outside the building.

The building model validation was used to bring the simulation results as close as possible with the real condition. The dwelling was modelled by using DesignBuilder and IES VE 2018 software, which is the integrated building performance analysis software to determine indoor temperatures, relative humidity and energy use (Andarini et al., 2009; Reeves et al., 2012). The building shape was based on the plan provided by the homeowner as a guidance; building materials information were from the contractor's building specification; and the occupant activity schedule, cooling systems, lights and appliances were gained from field observations. It then provides a description of the type of tests undertaken out for validation purposes and provides a description of the results obtained for a sample of the experimental runs performed.

Measured data were used on the empirical validation of the DesignBuilder software and IES VE 2018 model. The building simulation air temperature and relative humidity results will be compared with the building air temperature and relative humidity measured data. To be able to make a comparison, the modelled house was simulated in the same period as the monitoring time period. The software simulation result was compared with measured period data in two different period: dry season which has comparatively high weekly air temperature and a larger gap of temperature differences between maximum and minimum temperature, and rainy season which have relatively warm temperature and high relative humidity. The accuracy of the results is then discussed.

6.2 Validation of DesignBuilder software

As described in Chapter 5.2, there were two approach made on to validate the DesignBuilder software. The first approach was by using a study by Doris Hooi Chyee Toe in Johor Bahru,

Malaysia (Toe et al., 2015), that investigated the effectiveness of night ventilation for residential buildings. And the second approach was by using measured data gained from field measurement of the case study house.

6.2.1 Using night ventilation study in Johor Bahru

A study that investigated the effectiveness of night ventilation technique for residential buildings in Johor Bahru – Malaysia was chosen (Figure 6-1) to validate building model in DesignBuilder software. The study was conducted to study better thermal comfort for occupants in Malaysian terraced houses by creating field experiments (Toe et al., 2015). The field experiment examined the effects of night ventilation techniques on the indoor thermal environment for Malaysian terraced houses, focusing not only on the daytime thermal conditions but also on the night-time thermal conditions. The model of this Malaysian terrace house was constructed using the DesignBuilder software and simulated the same situation as for the field experiment. This DesignBuilder validation experiment imitated the night ventilation condition that was used in the field experiment simulation.



Figure 6-1 Malaysian terrace houses (Kubota et al., 2009).

Johor Bahru in Malaysia is located near the Equator with a hot and humid climate which is similar to the climate of Jakarta. The study about night ventilation for residential buildings was conducted to study better thermal comfort for occupants in Malaysian terraced houses through field experiments (Toe et al., 2015). The field experiment examined the effects of night ventilation techniques on the indoor thermal environment for Malaysian terraced houses, focusing not only on the daytime thermal conditions but also on the night-time thermal conditions.

6.2.1.1 Creating the Johor Bahru building model in DesignBuilder

The two terrace houses that were monitored were located side by side, identical in terms of design, size, construction, and materials. Field experiments in the selected houses were carried out from June to August 2007 under unoccupied and empty conditions (Kubota et al., 2009, p. 832). The experiment was conducted in the relatively dry season as there was no effect of the southwest monsoon in Johor Bahru. The measurement equipment was in the master bedroom on the first floor because on the survey findings that existing households used air conditioners mainly in master bedrooms. Indoors measuring sensors were placed at 1.5 m height from the floor and the data were recorded at 10 min intervals. The measured parameters were air temperature, relative humidity, air velocity and globe temperature (Kubota et al., 2009, p. 833). The houses were unoccupied and unfurnished during the experiment. A weather station was installed outside the house, in the car park, to record climatic parameters such as air temperature, relative humidity, wind speed and direction, barometric pressure, rainfall, and horizontal global solar radiation.

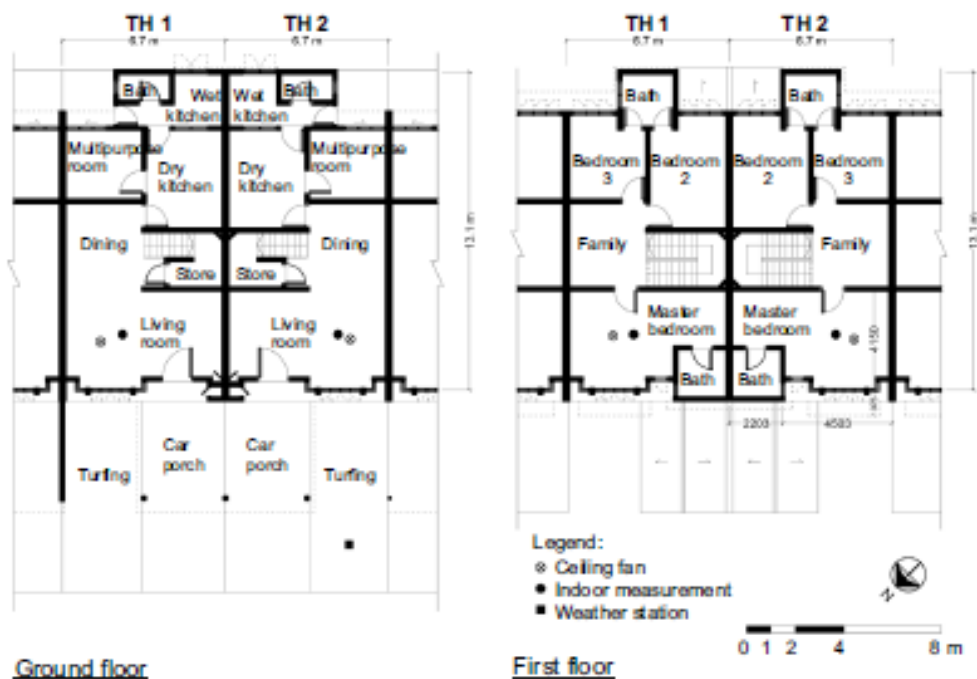


Figure 6-2 Malaysian terrace houses plan (Kubota et al., 2009).



Figure 6-3 Malaysian terrace houses monitoring equipment location (Kubota et al., 2009).

The selected house's total floor area is 155m². The building structure is reinforced concrete with plastered brick walls of 240mm for party walls, and 140 mm thickness for all other walls (Kubota et al., 2009). The floors were reinforced concrete slabs of 100mm thick and finished with ceramic tiles on the ground floor and timber strips on the first floor. Cement boards of 3.2mm thickness were used on the first-floor ceiling without insulation, and 6mm thickness cement boards are used in master bedroom. Concrete tiles were applied to the roof with a thin layer of double-sided aluminum foil under the roof tiles as radiant barrier. Windows were either casement or sliding type with 6 mm thick single glazed clear glass with aluminium frame.

The Johor Bahru terraced houses, as explained before, was modeled for the purpose of building model validation in DesignBuilder software. The model of this Malaysian terrace house was made in DesignBuilder software and simulated in the same situation as the field experiments. The building construction detail and activity schedule are listed in Appendix A and Appendix B respectively. This building model validation experiment was imitating the

night ventilation condition that was happening in the field experiments. Building data that were available were used to make a complete model and the field experiment data were used to validate the DesignBuilder simulation result. To simplify the modeling process, house 2 was chosen in this DesignBuilder validation process. Under the night ventilation conditions, all windows and doors were closed from 08.00 until 20.00 and were opened from 20.00 until 08.00. Figure 6-4 shows the preview of the building model in DesignBuilder software.

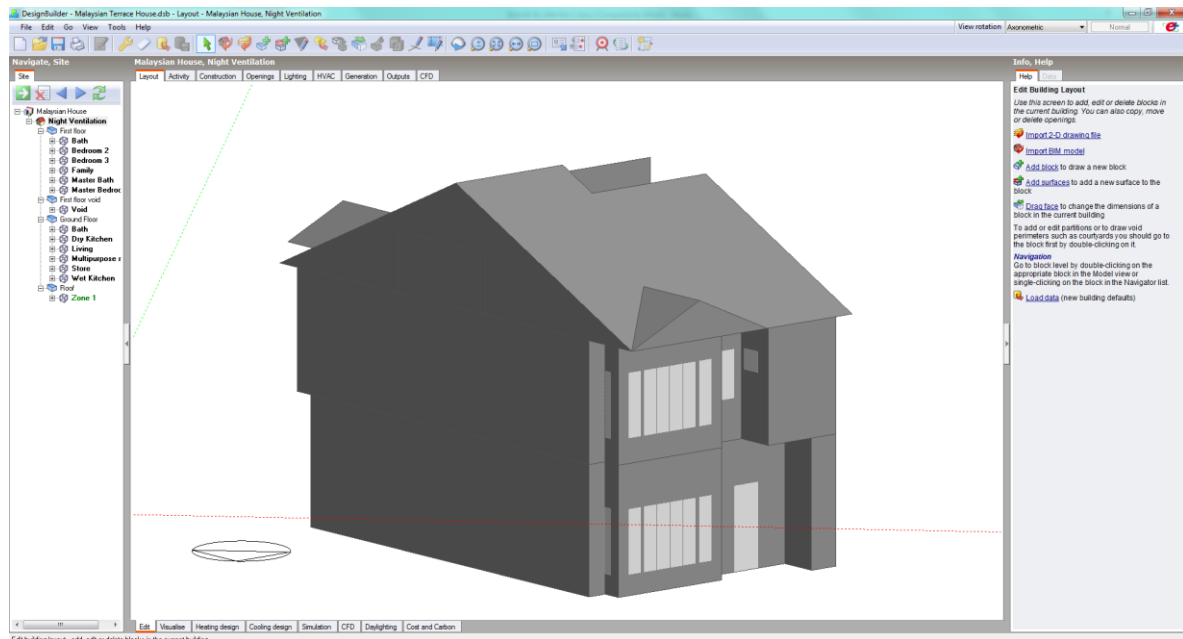


Figure 6-4 Building model preview in DesignBuilder software.

The model's geographical location using the actual terrace house coordinates: $1^{\circ}31'20''\text{N}$ and $103^{\circ}38'23''\text{E}$ and at an elevation of 21.3m above sea level. The building was oriented towards northwest, which means that the external façade of the master bedroom faced northwest. The 15-minute intervals weather data that was measured on site throughout the field experiment period from 20 June - 29 August was used in the simulation. The weather data used in the DesignBuilder simulation were measured on site or obtained directly from the local meteorological station. The raw weather data covered dry bulb temperature, relative humidity, wind speed, wind direction, barometric pressure, and global horizontal solar radiation.

6.2.1.2 Building model validated

Building data and building simulation by Doris (Toe, 2013, p. 128), were used to developed building specification and reference U-value for the computer modeling. Table 6-1 shows the building data that is used in design builder software model.

Table 6-1 Constructional layers and reference U-values of the base model.

Building element	Constructional layers	Reference U-value (W/m ² K)
External and internal walls	20mm thick cement plaster + 100mm thick clay brick + 20mm thick cement plaster	2.75
Party wall	20mm thick cement plaster + 200mm thick clay brick + 20mm thick cement plaster	2.07
Ground floor	8mm thick ceramic tile + 22mm thick cement screed + 100mm thick concrete slab + soil layer	3.75
First floor (timber flooring)	15mm thick timber flooring + 15mm thick cement screed + 100mm thick concrete slab + 20mm thick cement plaster	2.81
First floor (ceramic tile flooring)	8mm thick ceramic tile + 22mm thick cement screed + 100mm thick concrete slab + 20mm thick cement plaster	3.29
Ceiling (master bedroom)	6mm thick ceiling board	3.62*
Ceiling (other zones)	3.2mm thick ceiling board	3.63*
Pitched roof	20mm thick concrete roof tile + 25mm thick timber batten + aluminium foil	2.67
Flat roof	22mm thick cement screed + 100mm thick concrete slab + 20mm thick cement plaster	3.37
Window	6mm thick single layer float glass (total solar transmission (SHGC) = 0.819)	5.78

* With the properties that thin fiber-cement ceiling boards have, the maximum U-value that DesignBuilder calculated was smaller compared with the manufacture's calculation (Toe, 2013).

Measured indoor air temperatures, relative humidity, and the corresponding outdoor climatic conditions for modelled building in DesignBuilder software were compared with the field measurements. Figure 6-5 shows that there is a 2°C air temperature differences on the first day of simulation, but the difference reduces during the week. From the middle of the week, the air temperature between field measurements and software simulation indicates similar results. Figure 6-6 shows that the simulation results having the same trend as the field measurements.

The different results for the first day of the week in the simulation are possibly due to some differences in the climate data used in the software simulation compared to actual local meteorological station data for the selected simulation date. Another possible reason is the circumstances of the measurements on site - all house windows were open for 24 hours a day before the experimental period. The relative humidity of the house also indicates the same

situation with the air temperature. Figure 6-7 shows that with $\pm 5\%$ differences, the graph indicates the same trend between simulation results and field measurement. Figure 6-8 indicates that the relative humidity shows the same shape between measured and simulation results.

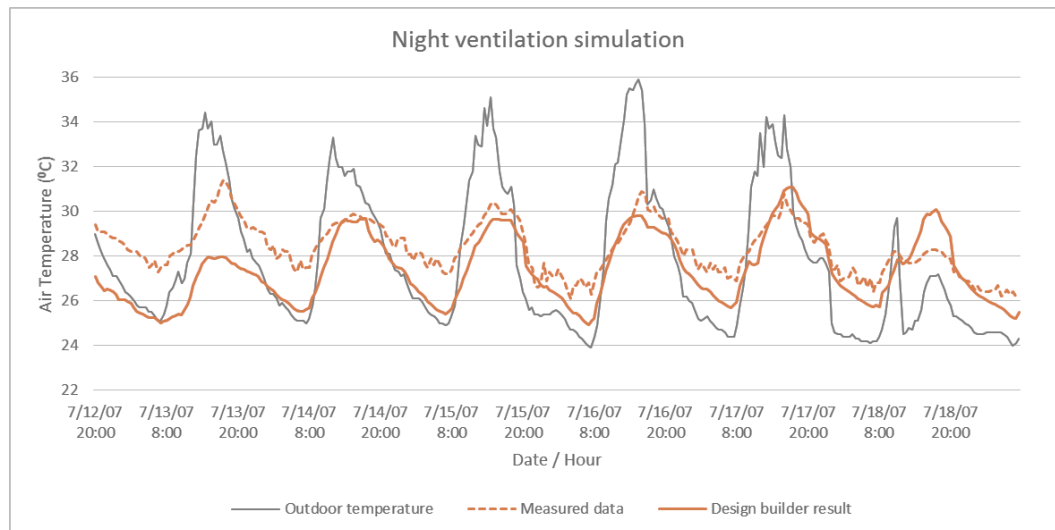


Figure 6-5 Night ventilation air temperature comparison for one-week period

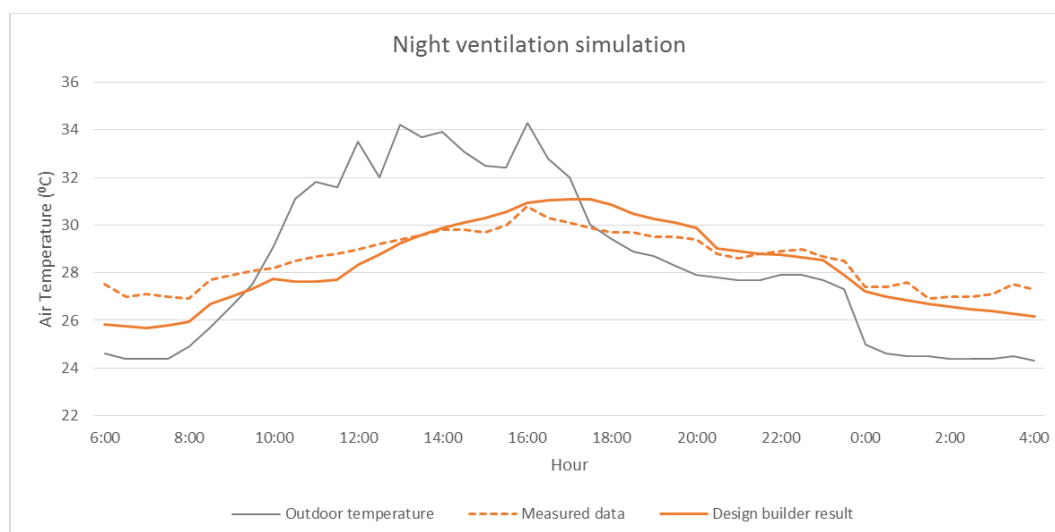


Figure 6-6 Night ventilation air temperature comparison for one day period.

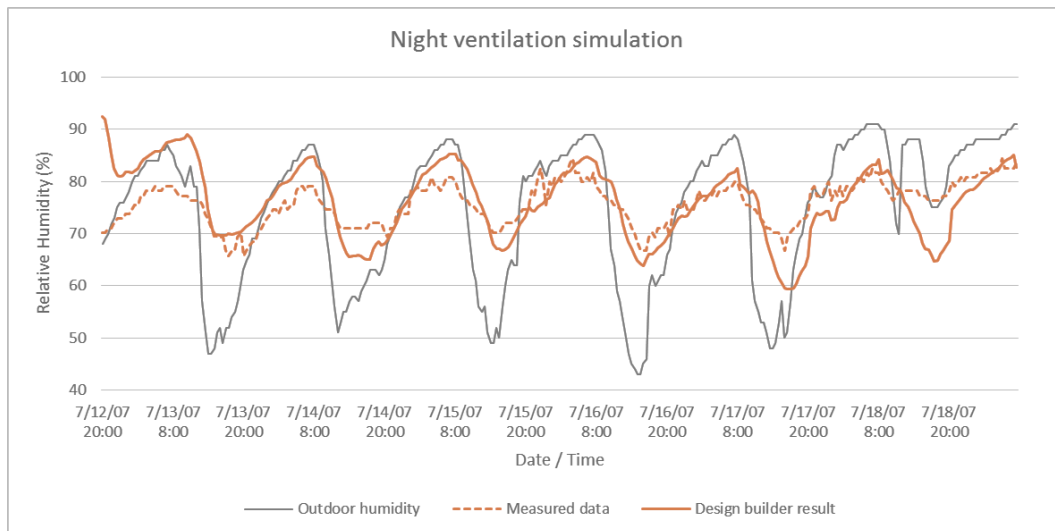


Figure 6-7 Night ventilation relative humidity comparison for one-week period.

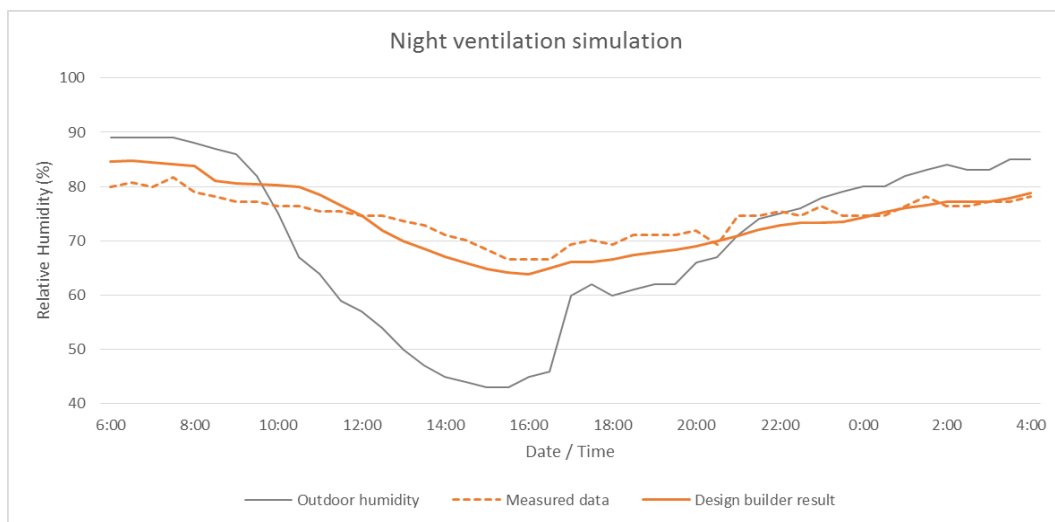


Figure 6-8 Night ventilation relative humidity comparison for one day period.

With this experiment, the terrace house in the hot humid climate modeled in DesignBuilder produced relatively similar results compared with the field measurement data.

6.2.1.3 Evaluation Indicators

To validate the built model in DesignBuilder statically, the adjustment and calibration process were conducted in accordance with the specifications of the Guideline ASHRAE 14-2002 (ASHRAE, 2002). The statistic MBE represents the mean ratio of relative error between two values, as shown in Equation 6-1, while CV/RMSE represents the average deviation between an actual value and a predicted value as shown in Equation 6-3. CV/RMSE values are used to assess the differences in the simulated and observed hourly data, to evaluate the prediction accuracy of the simulation result. ASHRAE Guideline 14 defines the acceptable limits for

calibration to hourly data as within $\pm 10\%$ MBE and $\leq 30\%$ CVRMSE (hourly) measured at a utilities level (ASHRAE, 2002). The measured data were compared with simulated data from IES VE building simulation.

$$MBE = \frac{\sum_{i=1}^{N_S} (y_i - \hat{y}_i)}{\sum_{i=1}^{N_S} y_i}$$

Equation 6-1

$$\hat{Y}_S = \frac{\sum_{i=1}^{N_S} y_i}{N_S}$$

Equation 6-2

$$CVRMSE_{(S)} = \frac{\sqrt{\frac{\sum_{i=1}^{N_S} (y_i - \hat{y}_i)^2}{N_S}}}{\hat{Y}_S}$$

Equation 6-3

where:

y_i : Recorded data

\hat{y}_i : Simulated data

N_S : Sample size

\hat{Y}_S : Sample means for recorded data

By inserting the measured and simulated data in to the calculation, the evaluation results of the statistical error analysis data for the mean hourly error of measured data versus simulation result were gain and listed in Table 6-2. The calculation was done for a week period. From the table it can be seen that the results of the simulation comfortably meet the acceptance criteria. The room's relative humidity and temperature MBE percentage are very

low and the CVRMSE percentage was on the acceptable limit range. From this analysis we can confirm that the model in DesignBuilder software was validated.

Table 6-2 Statistical error data for the mean hourly error of measured data versus simulation result

Measured Element	MBE (%)	CVRMSE (%)
Relative humidity	-1.07	9.79
Air temperature	0.17	0.26

6.2.2 Using case study's field measurement data

The next building model validation process was using the case study house that was described in Chapter 4.4. The case study building data were used to build a dwelling model in DesignBuilder. By using site measurement data and building information, the building model in DesignBuilder was created. Dwelling plan and sketch-up file from the building owner and site inspection was used to produce the building model in DesignBuilder. The model's building element were using construction information from the case study dwelling that listed in Table 6-3. The building was oriented towards north, which means that the external façade of the children's bedroom faced north.

Table 6-3 Building element description for DesignBuilder building model.

Building Element	Constructional layers	U- Value (W/m ² K)
External and internal walls	25 mm thick cement plaster + 100 mm thick clay brick + 25 mm thick cement plaster	2.894
Party wall	25 mm thick cement plaster + 200 mm thick clay brick + 25 mm thick cement plaster	2.244
Floor	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + soil layer	3.264
Window	6 mm thick single layer glass (total solar transmission (SHGC) = 0.819)	5.778
Ceiling	6 mm thick gypsum board	3.125
Pitched roof	20 mm thick roof tile + 25 mm thick timber batten	6.061

The occupant activity schedule for the dwelling model was made based on the field observations that was described in Chapter 4.6. The real activity was made into typical activity

to match the DesignBuilder software system. In this building model validation in DesignBuilder software, the climate data was using real measurement on site, to make the building model situation as close as possible with the real condition. Analysis graph will be shown in four selected periods that cover two main seasons in Indonesia that is rainy season and dry season.

6.2.2.1 Initial building model

DesignBuilder model validation were made by making a comparison of the modeled house performance with measured data for the same period as the monitoring time period. Using the field measurement data that was described in Chapter 4.4, the empirical validation of the DesignBuilder model was determined by comparing the simulation results with the house field measurement data. Two room in the house were selected to be monitored - the living room and master bedroom. The dwelling model preview in DesignBuilder software can be seen in Figure 6-9.

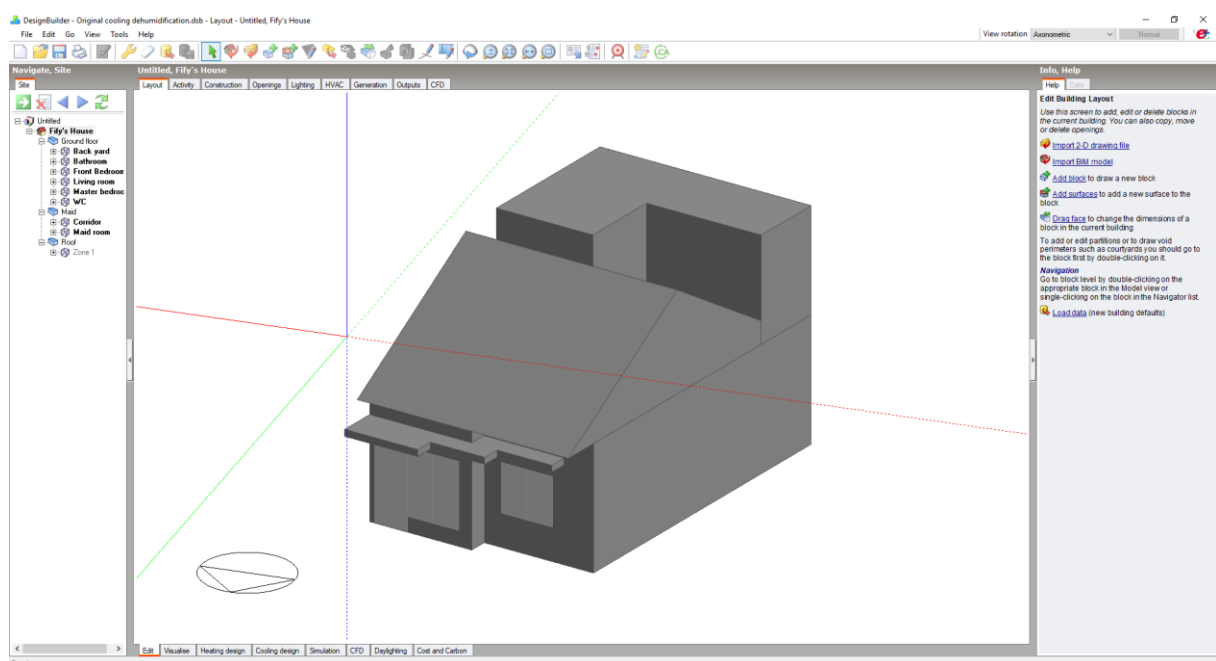


Figure 6-9 DesignBuilder model preface for the case study house.

The previous experience in using DesignBuilder software to validate the building model of Johor Bahru dwelling was used to validate the case study dwelling in DesignBuilder. This experience has accelerated the process of making building models from the case study house into DesignBuilder software. Since the construction type and material were relatively the same between Johor Bahru (Malaysia) and Jakarta (Indonesia), the building material

information from the validated Johor Bahru building model in DesignBuilder was used in creating the case study building model in DesignBuilder. The initial construction details and DesignBuilder occupancy settings for the validation process are presented in Appendix A and Appendix D respectively.

With all the building information added into the dwelling model in DesignBuilder, the simulation was run to look at the building air temperature and building relative humidity in the same period of site measurements. The initial model's performance can be seen in Figure 6-10 and Figure 6-11. From the graph can be seen that by inputting the building information about the case study dwelling to the DesignBuilder software, the air temperatures from the building model were fluctuating strongly, with some air temperatures much higher than outdoor temperature and at some periods lower than outdoor temperature. The measured temperature had a different condition, where measured data indicated more stable temperatures with small fluctuations, that mainly above the outdoor air temperature. The window opening time was playing a big part in creating this air temperature differences between simulation and measurement results. The initial opening window schedule suggested the window was not closed during the days, which is what happened in the initial model building (compare point 2 in Appendix D and Appendix E).

For the building model's relative humidity, the graph indicates relatively higher relative humidity results compared to the measured relative humidity. There were some periods when the simulated relative humidities were above the outdoor relative humidity, whereas the measured relative humidity was mainly below the outdoor relative humidity. During this initial validation process, the measured data gained was still from the rainy season period January to February.

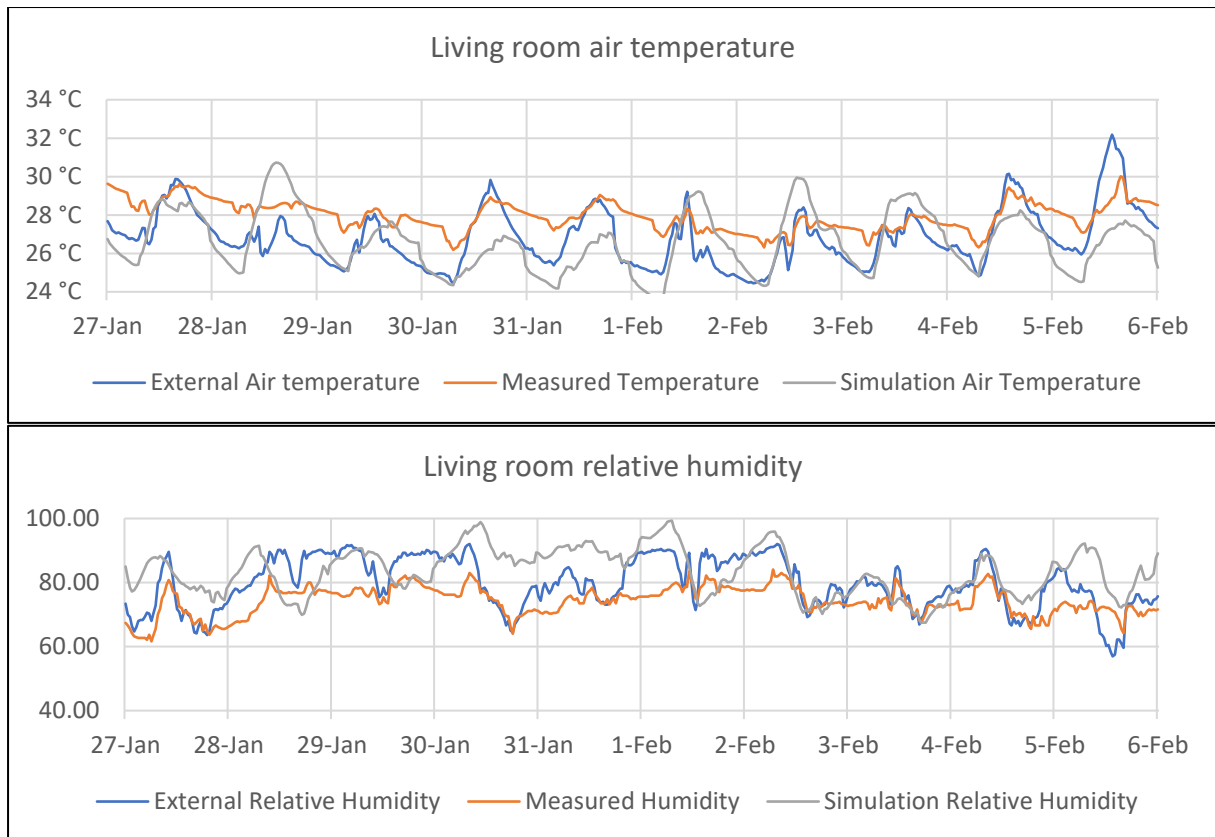


Figure 6-10 Initial DesignBuilder's model simulation result for living room area

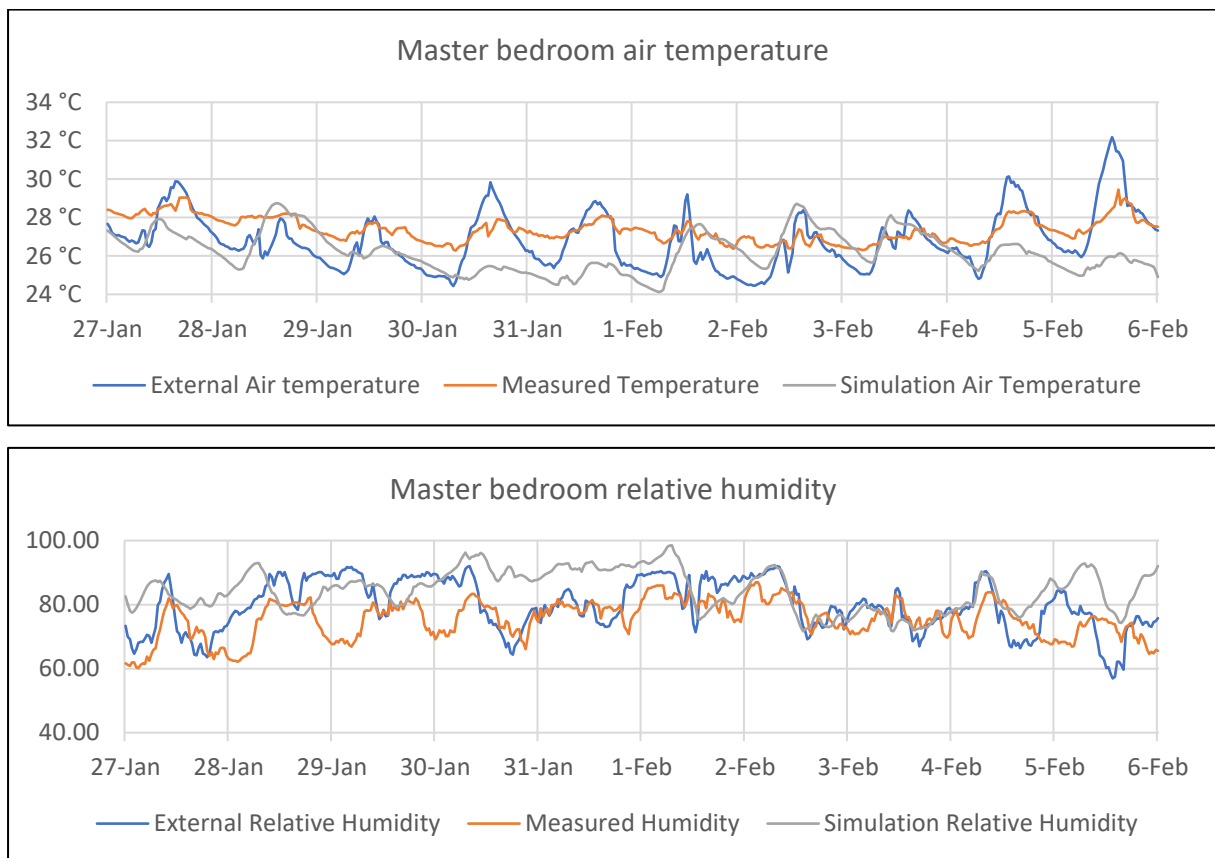


Figure 6-11 Initial DesignBuilder's model simulation result for master bedroom area

6.2.2.2 *Building model validated*

The initial findings suggested an adjustment to the building model in DesignBuilder. Some possible reasons that made the simulation results of the initial building model different from the measured data were the selected occupancy setting, the schedule of window opening time, and the room definition for each room in the house. Since the initial model was using the same typical activity for all the rooms in the house, so the changes were made by adjusting the initial activity. These changes were to create a different activity schedule for each room, mainly on the living room and master bedroom where the main research done (Appendix E).

The occupancy schedule was slightly different from day to day, meanwhile, the setting for the building model was made typical for weekdays. An adjustment was made in the schedule that represented the typical days. The room activity schedule was still made typical and based on the activity held during the measurement. The same situation with the schedule of window opening time was made typical and the same time match the real condition. The significant changes in the model simulation was the changes in the living room area definition. In the initial analysis the living room was made different with the kitchen area, whereas in reality these rooms are without any physical partition. Therefore, the next analysis was to include the kitchen area in the living room area.

With the adjustment made based on the analysis of the initial simulation results, the simulation of the revised building model was then made. The result of the simulation can be seen in Figure 6-12 and Figure 6-13. In the graph can be seen that for the period 27 January – 2 February, the outdoor temperature and measured indoor temperature are relatively the same. For this rainy season period, the graph indicated the same fluctuations with differences between measured air temperature and simulation air temperature of less than 1°C. The temperature fluctuation for this period was very small, with a 2 - 3°C gap.

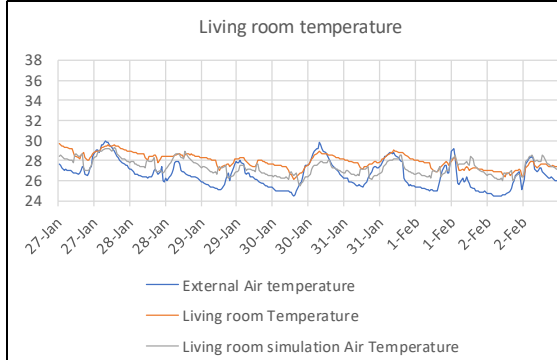
For the 14 – 20 September period, Figure 6-12 and Figure 6-13 indicated that the outdoor air temperatures were having very large fluctuations with the highest temperature at 36°C during the day and the lowest temperature was 26 °C during the night time. In this period, the air temperature in the living room and master bedroom was also fluctuating with 4°C differences between the maximum and minimum temperatures. The graph indicated that the air temperature from measurement and DesignBuilder simulation result has the same fluctuation and has relatively the same temperature with $\pm 1^\circ\text{C}$ differences. In the master

bedroom the temperature differences were even smaller with the simulated and measured lines close to each other. In this period can be seen also that the simulation air temperature has significant differences with the external temperature. With the updated activity schedule, the building model air temperature has the same fluctuation with measured data.

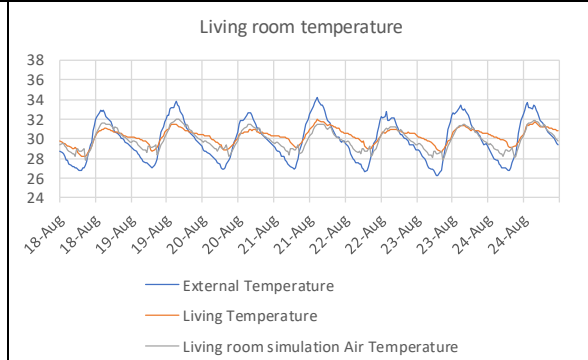
Following the air temperature analysis, the relative humidity analysis for living room and master bedroom were made. The graphs in Figure 6-14 and Figure 6-15 are indicating that measured relative humidity and simulated relative humidity results have the same fluctuation with $\pm 10\%$ differences for small periods of time. The simulated relative humidity fluctuation was also following the measured relative humidity. Graphs on 18 – 24 August, 14 – 20 September, and 29 October – 5 November shown in Figure 6-14 and Figure 6-15 indicate that the simulated relative humidity was very close with the measured relative humidity in the same period. But there were different results indicated in the 27 January – 2 February graph in Figure 6-15, where there was a sudden drop in relative humidity when the air conditioning was turned on. The drop was significant because the setting for AC was made the same for the whole simulation, but for 27 January – 2 February period the relative humidity differences between maximum and minimum was greater than for any other period.

A blow-up graph for 16 – 17 September was made to give a clearer view of the correlation between measured air temperature and simulation result air temperature. In Figure 6-16 can be seen that the measured and simulated result has the same fluctuation with less than 1°C temperature differences. The master bedroom graphs clearly indicate that the measured and simulation result is side by side. The relative humidity blows up graph in Figure 6-17 specify that the measured and simulated relative humidity result is also going hand in hand with $\pm 10\%$ alterations for a few hours in a day period.

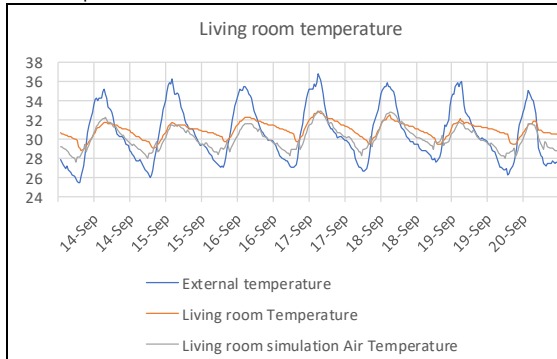
27 January 2017 - 2 February 2017



18 - 24 August 2017



14 - 20 September 2017



29 October 2017 - 5 November 2017

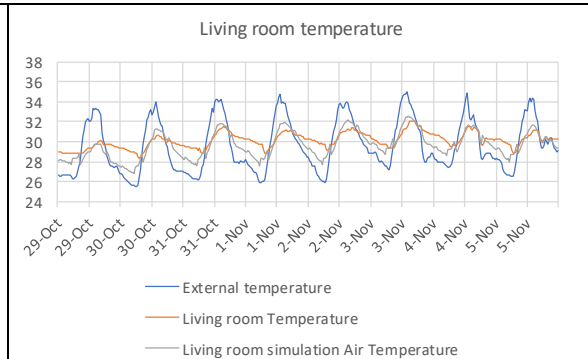
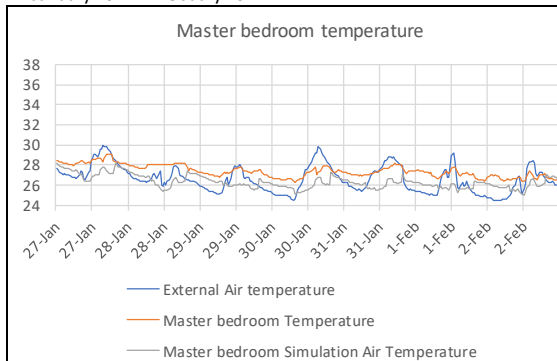
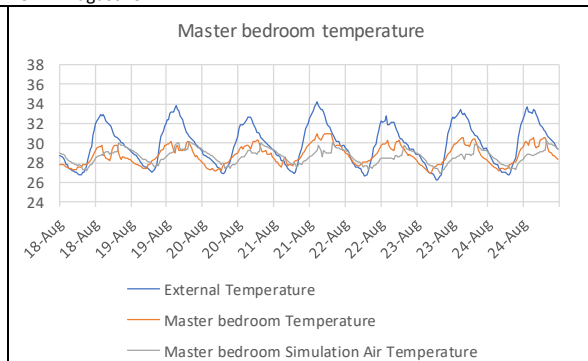


Figure 6-12 Living room air temperature comparison between site measured data and DesignBuilder simulated data.

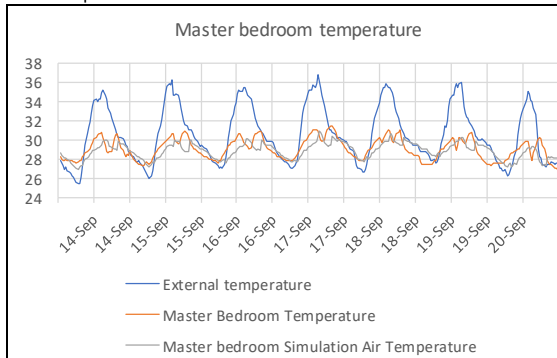
27 January 2017 - 2 February 2017



18 - 24 August 2017



14 - 20 September 2017



29 October 2017 - 5 November 2017

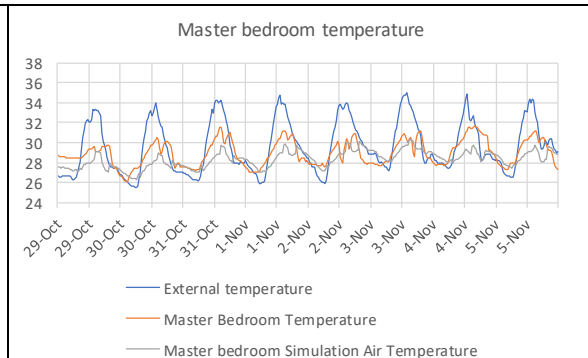
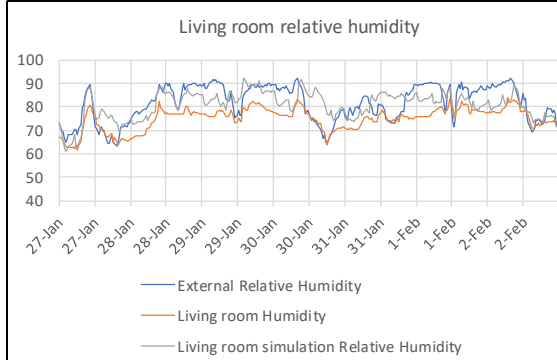
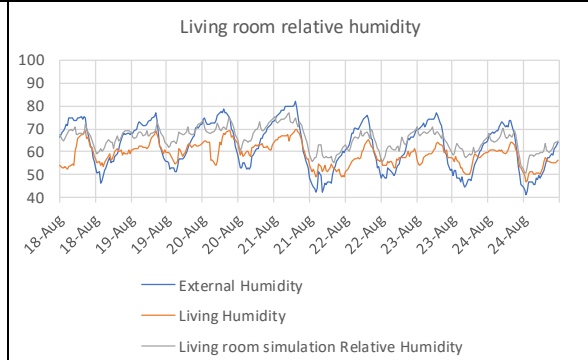


Figure 6-13 Master bedroom air temperature comparison between measured data and DesignBuilder simulated data.

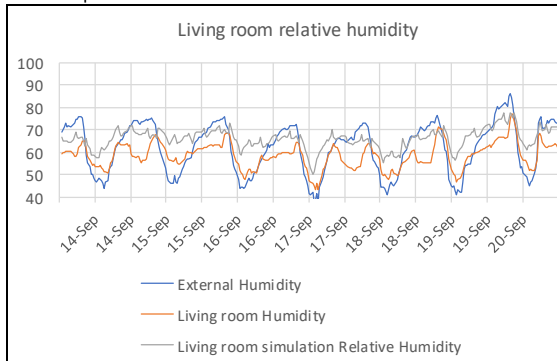
27 January 2017 - 2 February 2017



18 - 24 August 2017



14 - 20 September 2017



29 October 2017 - 5 November 2017

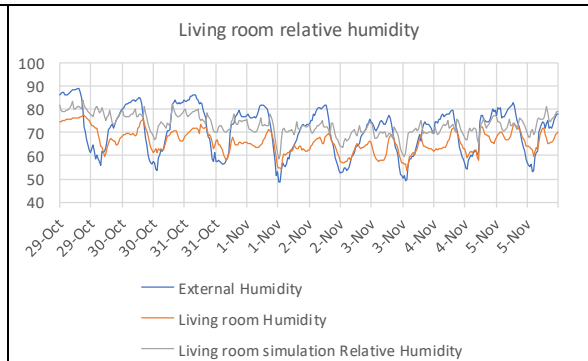
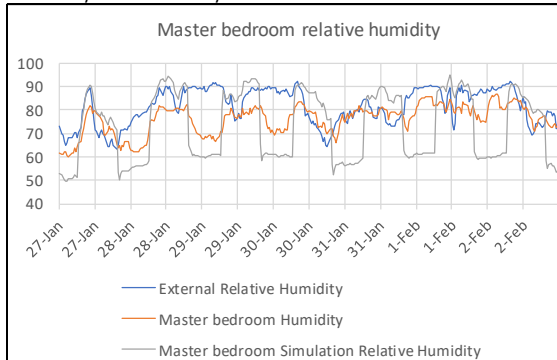
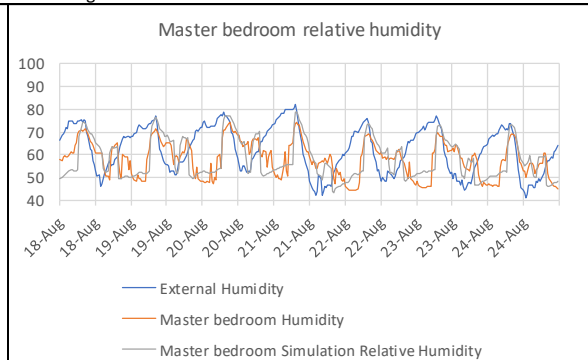


Figure 6-14 Living room relative humidity comparison between site measured data and DesignBuilder simulated data.

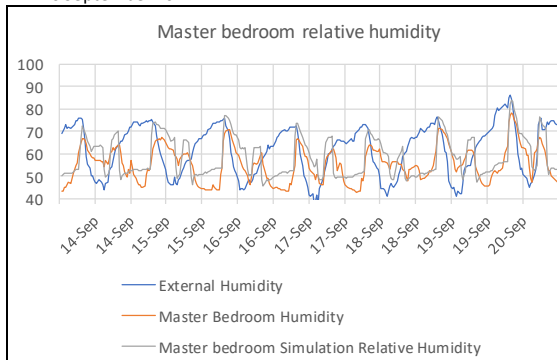
27 January 2017 - 2 February 2017



18 - 24 August 2017



14 - 20 September 2017



29 October 2017 - 5 November 2017

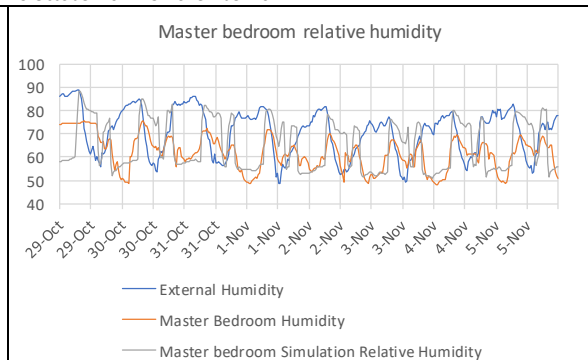


Figure 6-15 Living room relative humidity comparison between site measured data and DesignBuilder simulated data.

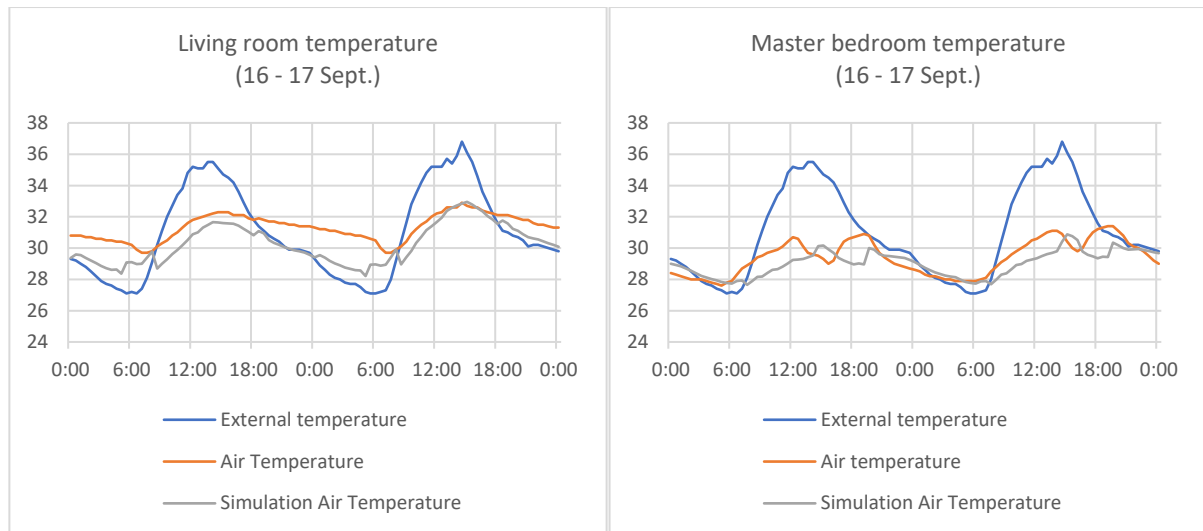


Figure 6-16 Air temperature comparison between site measured data and DesignBuilder simulated data from 16 – 18 September.

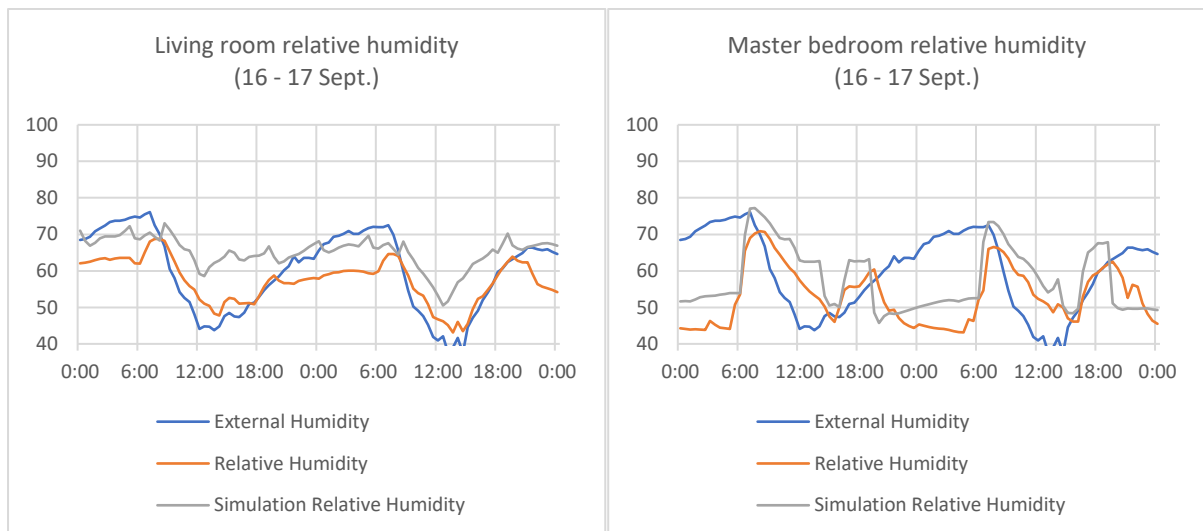


Figure 6-17 Relative humidity comparison between site measured data and DesignBuilder simulated data from 16 – 18 September.

The validation simulation results for the master bedroom and living room air temperature and relative humidity that were shown in the simulation results from the DesignBuilder building model were satisfactory in displaying the same trend as the measured data. The DesignBuilder building model performance indicated relatively the same results with the measured data for the same period from the case study building.

6.2.2.3 Evaluation Indicators

The measured data were compared with simulated data from DesignBuilder building simulation to validate the built model in DesignBuilder statically. By inserting the measured

and simulated data in to the MBE and CVMSE calculation, the evaluation results of the statistical error analysis data for the mean hourly error of measured data versus simulation result were gain and listed in Table 6-4. From the table it can be seen that the results of the simulation comfortably meet the acceptance criteria for CVMSE percentage for all period of time. But there was a high MBE calculation on the living room relative humidity, that were slightly above the acceptance limits. This result might be because the additional humidity from people activity that different on the daily basis but made typical on the schedule.

Table 6-4 Statistical error data for the mean hourly error of measured data versus DesignBuilder simulation result

Measured Element	MBE (%)	CVMSE (%)
29 October - 5 November		
Living room relative humidity	-10.98	11.96
Living room air temperature	1.48	0.15
Master bedroom relative humidity	-5.03	0.68
Master bedroom air temperature	2.04	0.21
27 January - 2 February		
Living room relative humidity	-7.87	9.06
Living room air temperature	2.24	0.17
Master bedroom relative humidity	3.70	0.88
Master bedroom air temperature	3.95	0.24
18 - 24 Augustus		
Living room relative humidity	-10.12	12.35
Living room air temperature	1.12	0.11
Master bedroom relative humidity	0.08	0.48
Master bedroom air temperature	0.51	0.18
14 - 20 September		
Living room relative humidity	-10.72	13.97
Living room air temperature	2.68	0.19
Master bedroom relative humidity	-5.48	0.56
Master bedroom air temperature	0.63	0.17

6.3 Validation of IES VE software

In the research process, IES VE was introduced to accelerate the study of the dehumidification process. Since the research had found that the high relative humidity was the main issue in the housing built in a hot and humid climate, the dehumidification needed to be applied in

the building model. To suits the needs on studying the dehumidification effects on the building, the HVAC system in the IES VE software was modified on the later process in this research. The readiness of HVAC template with dehumidifier and the availability of on demand tutorials, accelerated the process on studying the effect of the dehumidifier in the IES-VE building model. To be able to achieve the simulation result that close to the actual environment, a validation process was done for IES VE software. The empirical validation of the IES VE 2018 building model was determined by comparing the simulation results with the house field measurement data.

6.3.1 Built the building model in IES VE

The building model in IES VE was created by using the building information gained from site measurement. The building elements that were used to a create building model in IES VE was done by adapting the DesignBuilder building element information (Table 6-3) and putting the data in the IES VE format. The occupancy schedule was based on site observations that can be seen in Table 4-3 and with climate data that was gained from site measurements. The building model preview with the simplified adjacent building in IES VE 2018 software is shown in Figure 6-18.

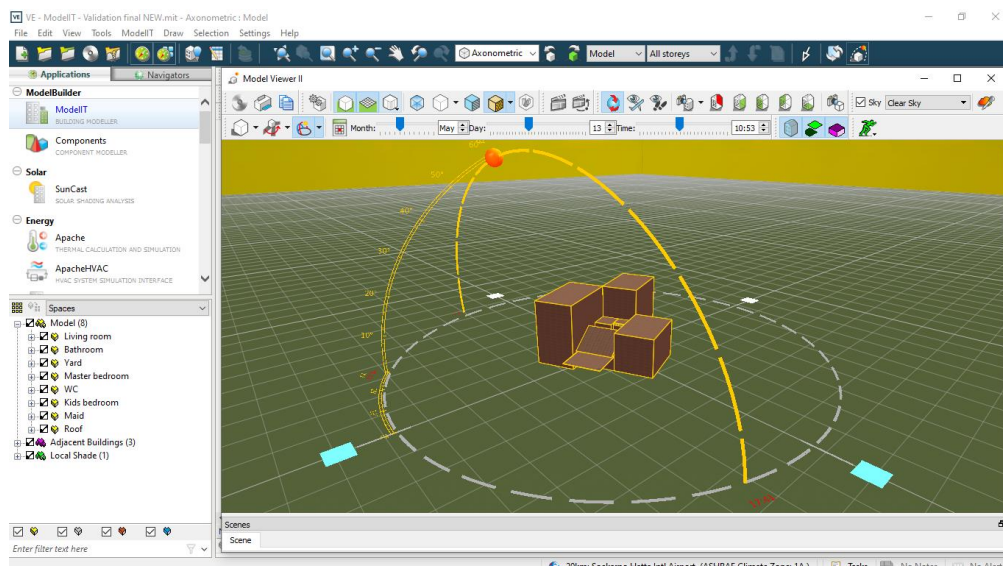


Figure 6-18 Dwelling model preview in IES VE 2018 software

6.3.2 Initial building model

The building model was created by applying the building information into IES software. The simulation was run to look at the building performance, and the results were then compared and analyzed with the measured data. The same analysis period as the DesignBuilder

validation was used. The IES VE validation process was also analyzed in four different period of time that represented the monitoring period on of the selected house. The initial construction detail and IES VE occupancy setting for validation process are presented in Appendix F and Appendix G respectively. The initial simulation results for living room and master bedroom area are shown in images below (Figure 6-19, Figure 6-20, Figure 6-21, and Figure 6-22). From the graph can be seen there were still differences between air temperature and relative humidity of the simulated and measured building.

This initial building model air temperature simulation result was following the external temperature in living room area. In general, simulated air temperature was following the external air temperature for the whole time. The identical situation was also happening in the master bedroom, where the simulated air temperature was following the external temperature. But the master bedroom simulated air temperature was lower compared with the measured temperature when the air-conditioning was in the 'on' position.

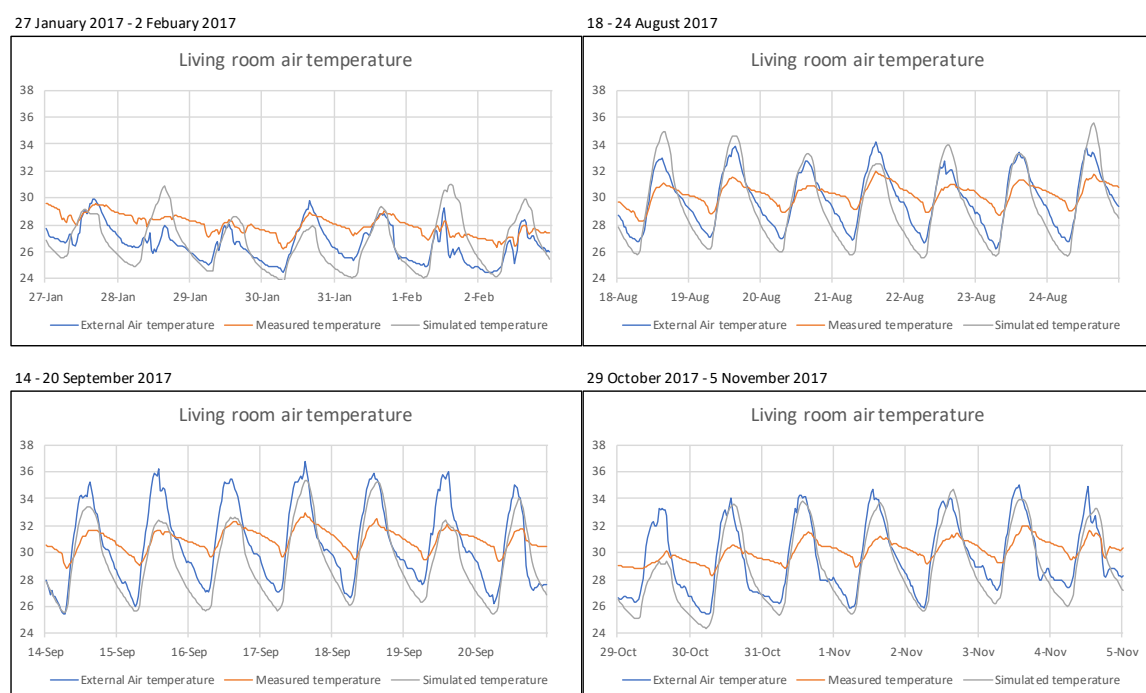


Figure 6-19 Living room air temperature comparison between site measured data and IES VE simulated data.

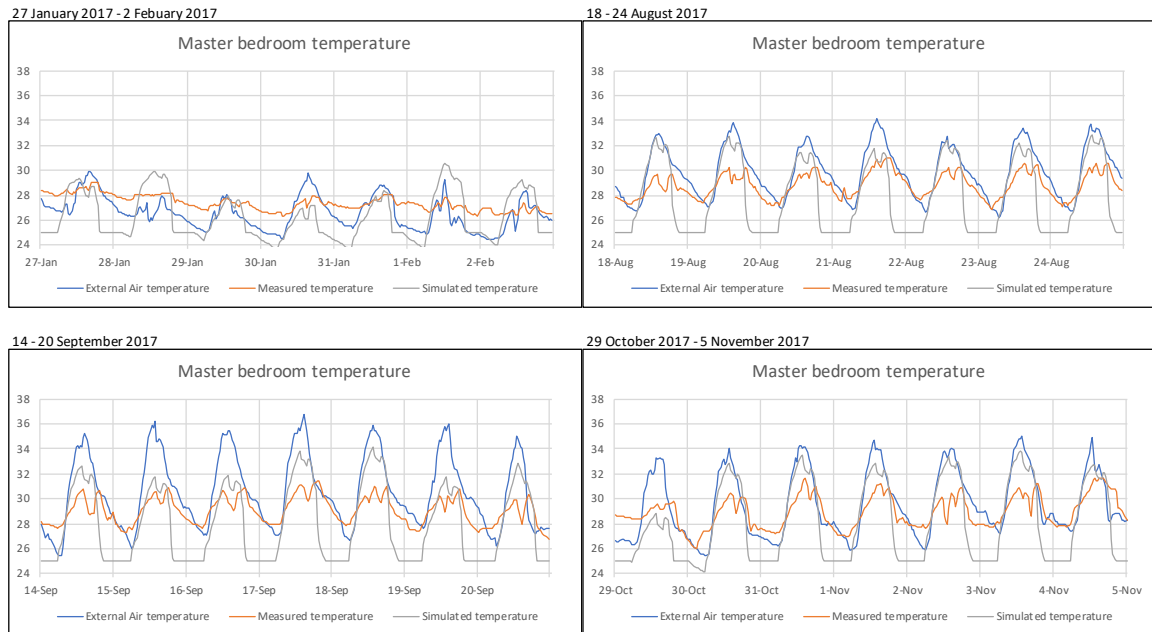


Figure 6-20 Master bedroom air temperature comparison between site measured data and IES VE simulated data.

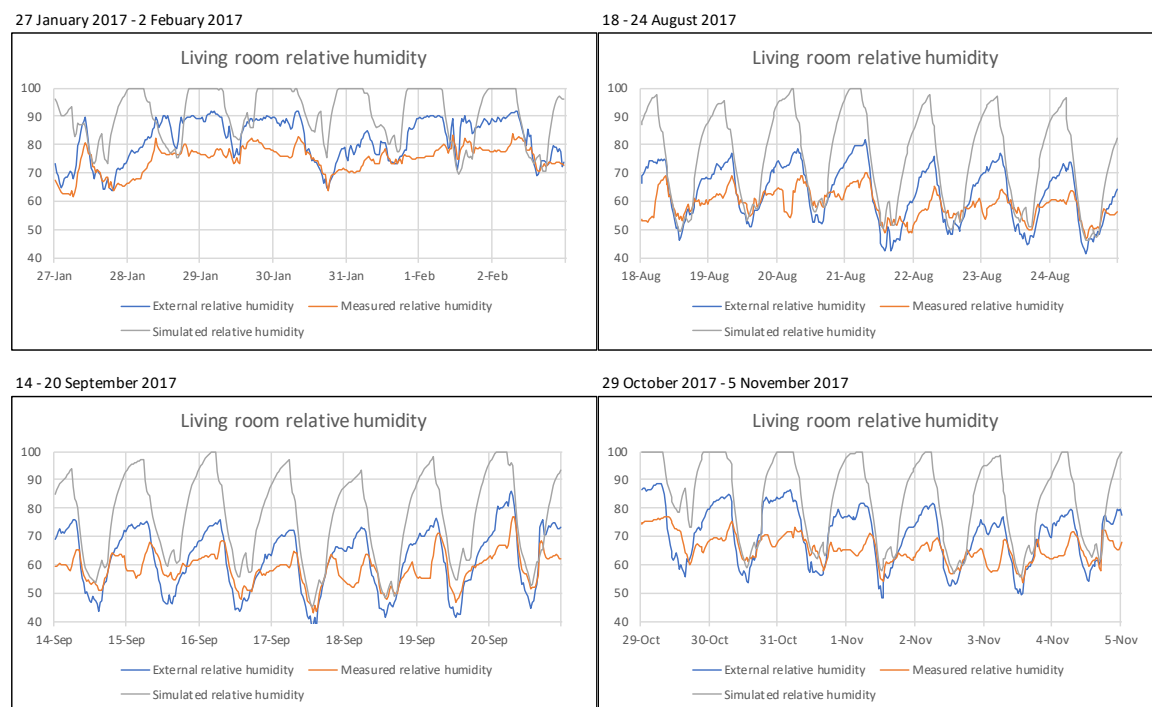


Figure 6-21 Living room relative humidity comparison between site measured data and IES VE simulated data.

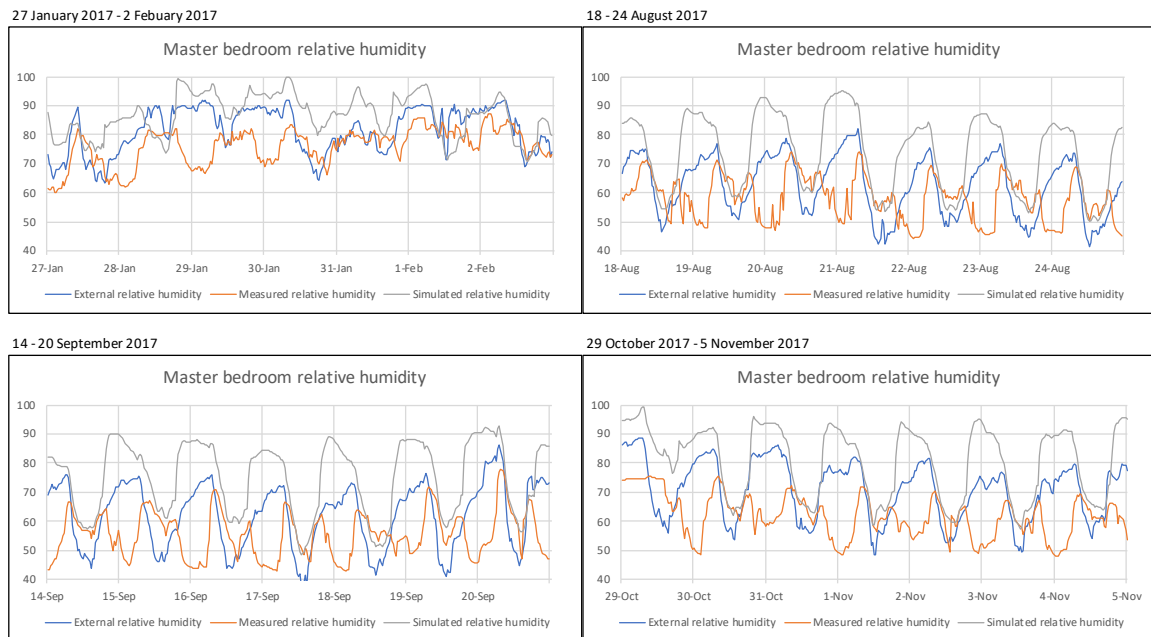


Figure 6-22 Master bedroom relative humidity comparison between site measured data and IES VE simulated data.

The initial simulated relative humidity results in the living room and master bedroom were also indicating as much higher relative humidity during night and morning time, and only showed the same result during the day for a short period. On the 27 January – 2 February and 29 October – 5 November period, the simulated relative humidity during nighttime can reach 100%, and this number was even higher than the external relative humidity. In the master bedroom, the simulated relative humidity was following the external relative humidity. While for real measurements, there was a phase when the bedroom relative humidity was showing a downward trend.

6.3.3 Building model validated

With the first attempt in creating the building model in IES VE, the simulation results indicated that the living room simulated air temperature was following the external temperature and the room's simulated relative humidity results indicated there was a sudden rise during the day compared to measured relative humidity. The air temperature behaviour in the master bedroom was following the external temperature during the day but with a sudden drop in the afternoon until the next morning. A possible reason was because the air exchange rate needed to be adjusted on the initial building model, to imitate the real condition, since the initial building model was using the default IES VE setting. The ground temperature was also needing to be amended, because the default ground temperature used in the IES VE model was using the same temperature as the outside temperature. With these analyses, the

adjustment was needed to the IES VE building model. There are three adjustments made on the initial building model's setting: changes on the ground temperature, changes on the model air exchange rate, and changes on the cooling system.

With the setting in the previous sub-chapter (initial building model), the air temperature and relative humidity simulation results of building model (Figure 6-19, Figure 6-20, Figure 6-21, Figure 6-22) indicate a large divergence between measured and modelled values, with simulation data showing internal air temperatures similar to the external temperatures. The building material was assumed to be correct since the information was collected from the validated building model.

The studies of the IES model indicated that the assumed ground temperatures were creating the divergence. The default setting in IES VE sets the ground temperature equal to the external air temperature, but this may not be appropriate for tropical weather and soil conditions. The software analysis indicated that an offset temperature profile set at - 5°C from the external temperature was appropriate for this simulation. The detail explanation about the ground temperature study can be found in chapter 8.

Since the air exchanges were not measured in the building, the air exchanges in the IES VE building model were then checked. All air exchanges represent air flow entering the space, with the source of the air coming from the external environment, an adjacent space or a supply at a temperature specified by an absolute profile. In IES VE software, the air exchanges are consist of three types: Infiltration, Natural Ventilation and Auxiliary Ventilation (IES-VE, 2018). Auxiliary Ventilation air exchanges are intended to be used to specify minimum levels of either mechanical or natural ventilation for fresh air purposes. If this convention is followed ventilation will be correctly handled in simulations for building regulation compliance.

The initial simulation was using the default air exchange setting in IES VE software. In the IES VE air exchange tab, the default setting for maximum flow condition in natural ventilation was 2ach, and the maximum flow for infiltration rate was 0.250ach. With the case study building not using insulation and a construction that had not considered building airtightness, the adjustment to mimic the real condition in the building model was made. The new value for natural ventilation was 5ach (IES-VE, 2017) and the building infiltration rate was adjusted

into 2ach. And the schedule for the window opening schedule listed in the Appendix G was used.

The big fluctuation on the simulated master bedroom relative humidity has suggested that an adjustment was needed on the building cooling system that needed to reflect the actual conditions on site. The HVAC methodology group in IES VE has the framework that can be used for modelling HVAC systems within the new project. The options are: Simplified (ApSystems) that uses a parametric approach based on Apache Systems, and detailed (ApacheHVAC) that uses component-based ApacheHVAC system models, and is integrated with a set of additional capabilities relating to HVAC zones, plenum spaces and advanced report formats (IES-VE, 2018). The initial model was using ApSystems, so the information inserted was very basic by inserting the information about cooling plant radiant fraction, cooling unit capacity and cooling set point. While in the revision version, the HVAC system was using slightly more detail information by using the IES VE HVAC template Figure 6-23. The AC schedule in the revision file was made typical throughout the week.

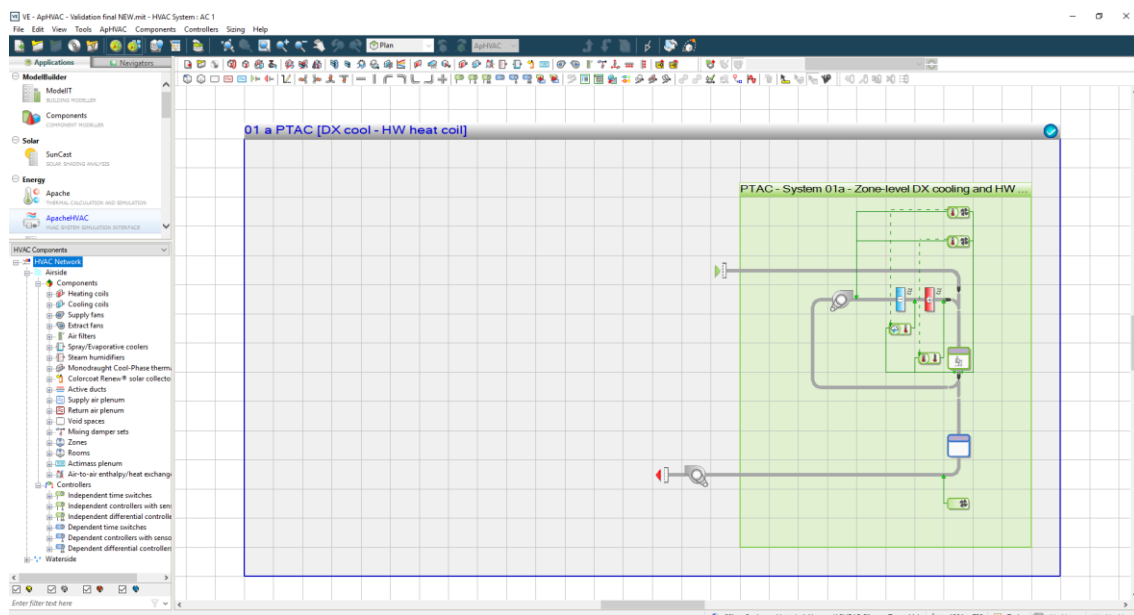


Figure 6-23 HVAC template preview in IES VE.

After running the simulation using the adjustment on the air exchanges and HVAC setting that mimic the real condition on the built model in IES VE, the results were discussed below. The simulation results comparison with measured data were compiled in Figure 6-24 to Figure 6-29. Living room simulation results in Figure 6-24 and Figure 6-25 indicated that the simulation results indicate the same fluctuation with the measured data, both for air

temperature and relative humidity. The differences in the air temperature were around 1°C to 2°C, and for the relative humidity was around 10%. In the bedroom area, the air temperatures had the same fluctuation between the modeled house simulation results with the measured data (Figure 6-26). On the other hand, there were a few days indicating relative humidity differences in the bedroom. From 9.00 until 18.00 there was a 10% drop in the simulated room relative humidity values (Figure 6-27). The temperature differences in the living room and master bedroom results were possibly happening due to logger accuracy and software simulation accuracy. The differences were also possible from the actual sky coverage and wind speed data that were not captured on the site measurements. Other possible reasons for the temperature and humidity differences are from occupant activities that were based on typical behaviors whereas the actual conditions might be slightly different from day to day. From this validation exercise, can be seen that model of the selected house in IES VE 2018 were produced relatively similar results compared with the field measurement data.

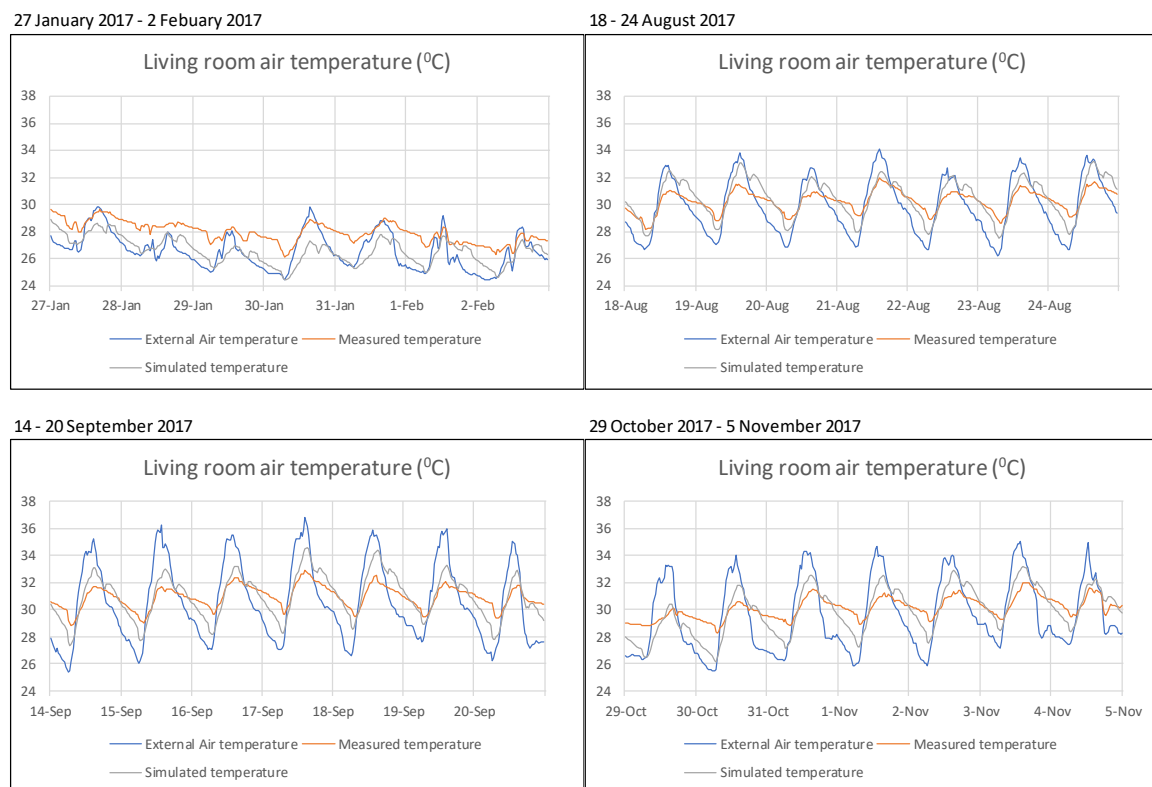
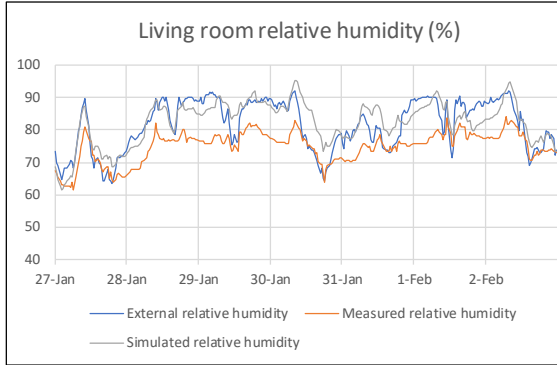
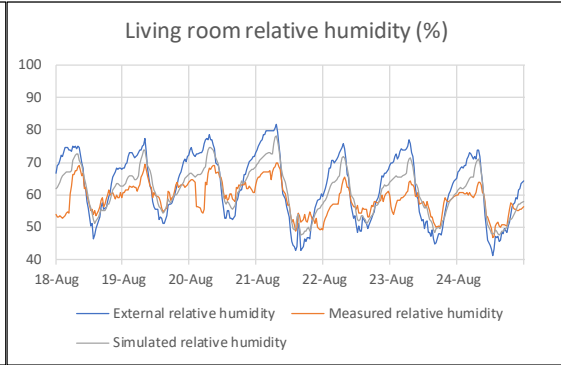


Figure 6-24 Living room measured air temperature and simulated air temperature comparison graph.

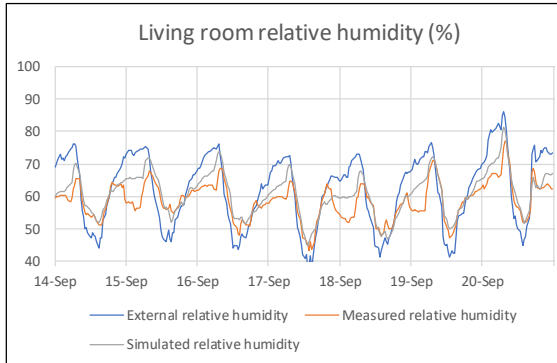
27 January 2017 - 2 February 2017



18 - 24 August 2017



14 - 20 September 2017



29 October 2017 - 5 November 2017

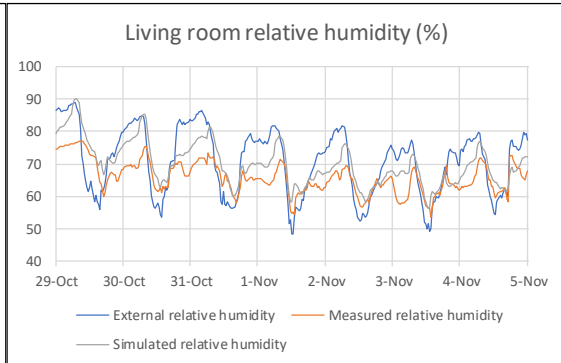
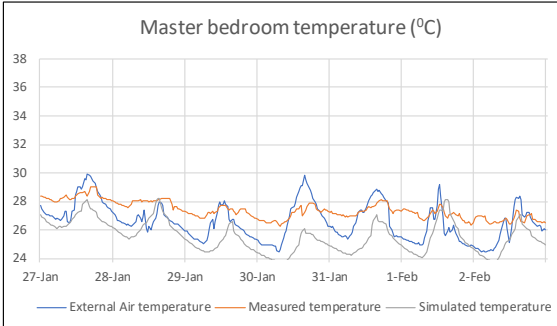
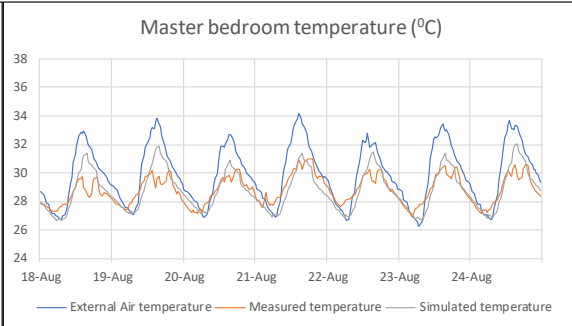


Figure 6-25 Living room measured relative humidity and simulated relative humidity comparison graph.

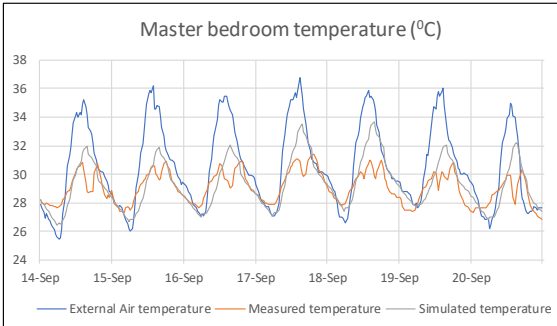
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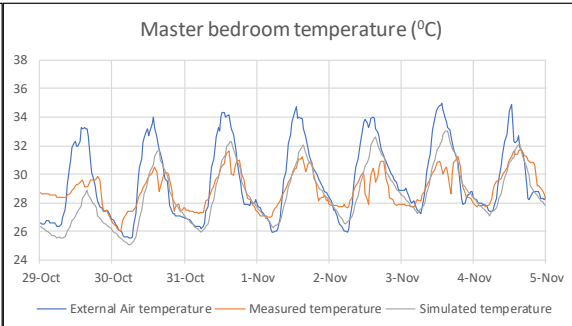
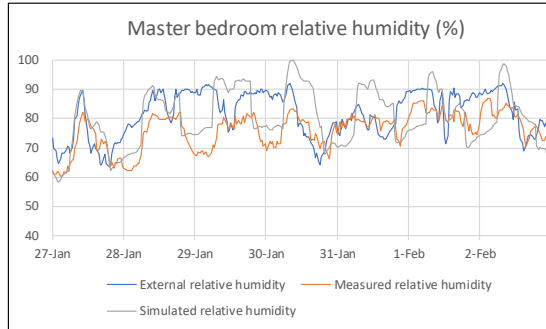
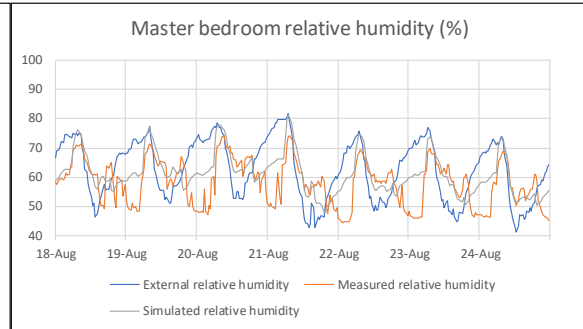


Figure 6-26 Master bedroom measured air temperature and simulated air temperature comparison graph.

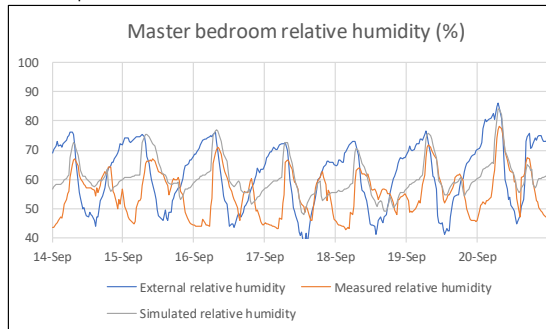
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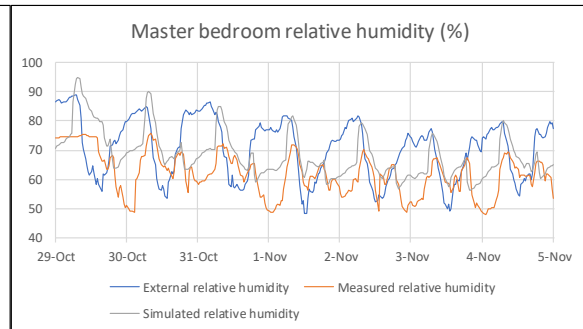


Figure 6-27 Master bedroom measured relative humidity and simulated relative humidity comparison graph.

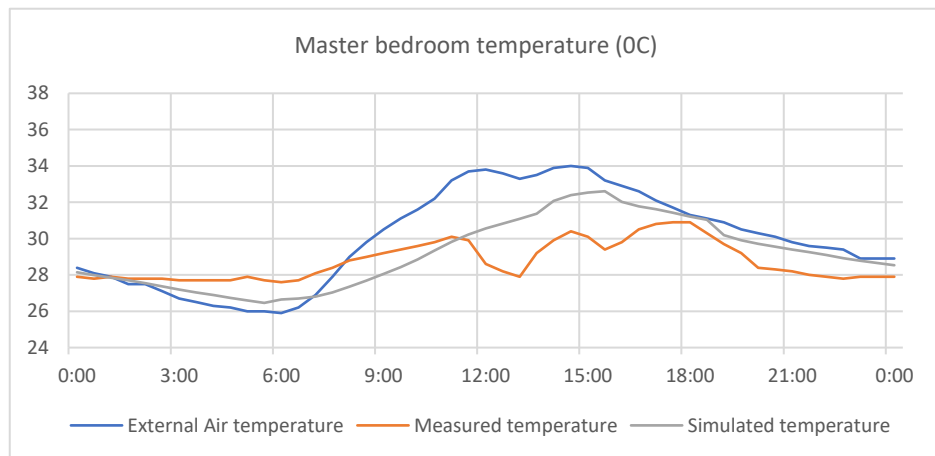
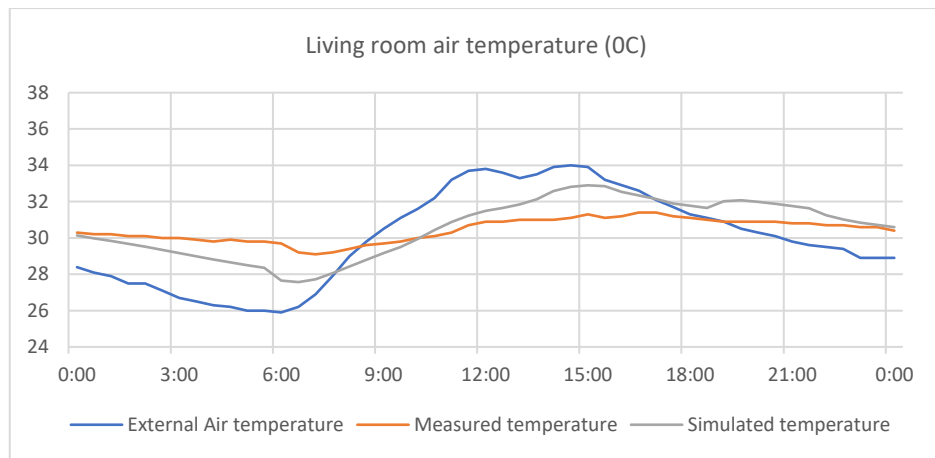


Figure 6-28 One day comparison (2nd November) of measured and simulated air temperature.

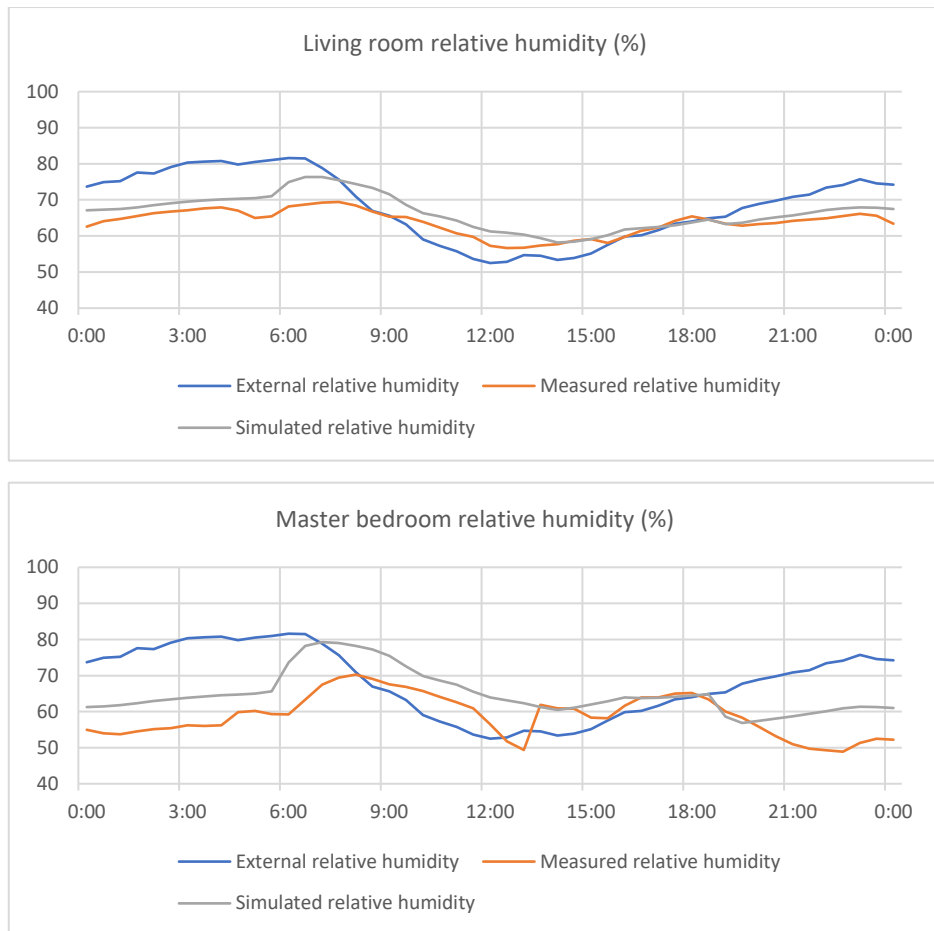


Figure 6-29 One day comparison of measured and simulated relative humidity.

A more detailed inspection (Figure 6-28 and Figure 6-29) shows that the simulation air temperature and relative humidity for one day was indicating with relatively the same fluctuation with slightly differences in the few hours during the day. From this validation exercise, it could be seen that the IES VE 2018 software could be used to model the selected house. The validation process indicated that the result produced relatively similar outcomes compared with the field measurement data. The simulation results of the built model in IES VE software shows that the results were satisfactory in displaying the same trend as the measured data.

6.3.4 Evaluation Indicators

To validate the built model in IES VE statically, the adjustment and calibration process were conducted in accordance with the specifications of the Guideline ASHRAE 14-2002 (ASHRAE, 2002). The statistic MBE and CV/RMSE are used to assess the differences in the simulated and observed hourly data, to evaluate the prediction accuracy of the simulation result. ASHRAE

Guideline 14 defines the acceptable limits for calibration to hourly data as within $\pm 10\%$ MBE and $\leq 30\%$ CVRMSE (hourly) measured at a utilities level (ASHRAE, 2002).

By inserting the measured and simulated data in to the calculation, the evaluation results of the statistical error analysis data for the mean hourly error of measured data versus simulation result were gain and listed in Table 6-5. The calculation was done for a week period. From the table it can be seen that the results of the simulation comfortably meet the acceptance criteria. The living room's relative humidity and temperature CVRMSE percentage are very low and was on the acceptable limit range. The MBE relative humidity percentage in the master bedroom was slightly above the limit, but the CVRMSE percentage was below 1% for the master bedroom.

Table 6-5 Statistical error data for the mean hourly error of measured data versus simulation result.

Measured Element	MBE (%)	CVRMSE (%)
29 October - 5 November		
Living room relative humidity	-6.30	7.84
Living room air temperature	0.70	0.17
Master bedroom relative humidity	-10.92	0.72
Master bedroom air temperature	1.28	0.22
27 January - 2 February		
Living room relative humidity	-10.00	10.92
Living room air temperature	4.82	0.28
Master bedroom relative humidity	-5.58	0.61
Master bedroom air temperature	6.79	0.40
18 - 24 Augustus		
Living room relative humidity	-3.77	7.95
Living room air temperature	-0.65	0.14
Master bedroom relative humidity	-5.38	0.65
Master bedroom air temperature	0.03	0.15
14 - 20 September		
Living room relative humidity	-3.62	6.16
Living room air temperature	-0.08	0.16
Master bedroom relative humidity	-9.39	0.79
Master bedroom air temperature	-0.89	0.22

6.4 Summary

In this research, two software were used to model the case study terrace house built in a tropical climate, DesignBuilder and IES VE. This chapter has explored the validating process for this two software. The DesignBuilder validating process from two measured data indicated that the simulation result had very similar results with the measurement data. DesignBuilder air temperature simulation result had the same fluctuation and had relatively the same temperature with $\pm 1^{\circ}\text{C}$ differences. For relative humidity, the analysis indicated that measured relative humidity and simulation relative humidity result had the same fluctuations with $\pm 10\%$ differences for a small period. With this analysis it can be seen that DesignBuilder can be used to model the selected case study house.

From this validation exercise can be seen also that the IES VE 2018 software can model the selected house in the tropical climate to produce relatively similar results compared with the field measurement data. From the IES VE validation process it can be see that:

- Simulation results indicated that the IES outputs had the same fluctuations as the measured data, both for air temperature and relative humidity.
- The differences in the air temperature were ± 1 to 2°C , and $\pm 10\%$ for the relative humidity.
- The relative humidity differences may be from the actual sky coverage and wind speed data not being captured at the measurement site.
- The other possible reason for the temperature and humidity differences is from occupant activities that were typical in the simulation, but in the actual dwelling might be slightly different from day to day.

The calibration calculation based on the guideline ASHRAE 14-2002 shows that the simulation results comfortably meet the acceptance criteria. The living room's relative humidity and temperature MBE percentage are on the acceptable limit.

Chapter Seven

7 APPLIED PASSIVHAUS STRATEGIES TO VALIDATED MODEL

7.1 Overview

To study the performance of the Passivhaus concepts in a tropical climate, the Passivhaus standards were applied into the validated house model in IES VE. Through IES VE simulation, the building performance was observed when the Passivhaus standards were applied. The same building layout, shape, and occupancy schedule were used while one or more Passivhaus criteria were applied to explore the effect of Passivhaus standards on the modelled house whilst trying to maintain the house's internal environment within the thermal comfort zone. The Jakarta's weather data from Meteonorm software was used on the energy building software to study the Passivhaus application. This study analyzed the effects of air conditioning (AC) and dehumidifiers on thermal comfort and cooling load.

Operative temperature is often considered a better indicator of thermal comfort as it combines both air and mean radiant temperatures in a space but is not easy to measure in real building situations. The loggers used in the site measurements recorded air temperature and relative humidity. The IES software was run to test for any significant differences between predicted air and operative temperatures in the house. The graph from the building validation in IES VE (Figure 6-28) was used to make a comparison between operative temperature and air temperature (Figure 7-1). The operative temperature for a selected day was extracted from IES VE software simulation and was compared with the air temperature.

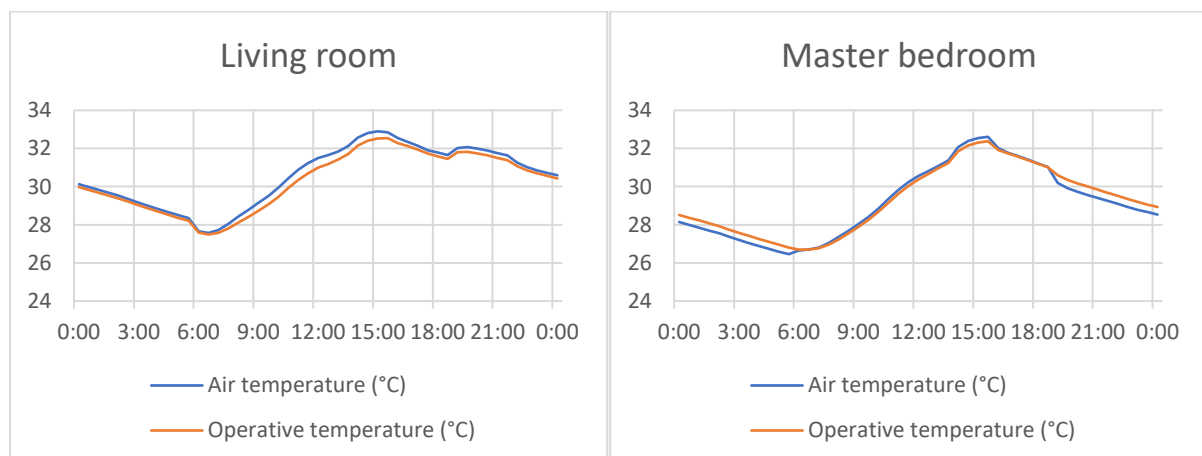


Figure 7-1 Air temperature and operative temperature comparison.

However, as shown in Figure 7-1, there were only minor difference between simulated air temperatures with simulated operative temperature and so it was feasible to use air temperature for the validation and the comfort analysis. This nearness of the two temperatures may be because the tropical conditions make all internal surfaces warm and the glazing area was relatively modest, leading to the air temperature being similar to the mean radiant temperature. In this thesis, the thermal comfort temperature will be based on air temperature.

7.2 PHPP analysis

In this initial study for Passivhaus application into a typical dwelling in Jakarta, the building model's performance were explored by using the PHPP application, which is the certified Passivhaus software. The building information such as building dimension, opening sizes, building material component, building orientation, and climate data was gained from the validated DesignBuilder and IES VE software. To suit the Passivhaus requirement, an additional construction layer was added to the building element, that is insulation. The initial model that was created in the PHPP was using the building elements that are listed in Table 7-1. The construction information, ventilation and cooling unit setting that were used in the PHPP software can be seen in Appendix P.

Analysis using PHPP was done to investigate the optimum material selection that was able to perform well in a hot and humid region and at the same time were energy efficient. By using the initial model, the performance of the building model in the PHPP program was explored by comparing the energy cooling demand when different building elements applied. The building component modification was focusing on three main building components, which were wall, roof, and floor; whereas other conditions were made constant that suited the Passivhaus criteria. The constants were the building shape, ventilation, climate data, and HVAC system.

7.2.1 Built the model in PHPP

The U-value of the building elements was calculated by PHPP by using the heat conductivities and building elements thickness that was entered into the software. The data in Table 7-1 indicates the heat conductivities and the thickness of the building assemblies that was registered into PHPP software. The weather data inputted in the PHPP was monthly weather

data gained from Meteonorm Software (Table 7-3). The cooling unit used in the building model built in PHPP software was an air-cooling unit with additional dehumidification, to cover the cooling demand and dehumidification process. The building model dimension inserted in the PHPP software were based on the site information gained from the owner information.

7.2.2 The simulation results

Using the information that was inserted in to PHPP software, the study was made by creating parametric study of different building elements U-value that was achieved by adjusted building elements thickness. Figure 7-2 shows the different building model's cooling demand from different combination of building material that gained from PHPP software. Different U-value indicated in the graph are representing the different wall insulation's thickness that was compared with several floor and roof material combination.

Table 7-1 Building elements heat conductivities and thickness for PHPP

		λ [W/(mK)]	Thickness [mm]	U-value [W/(m ² K)]
External wall	Interior plaster	0.5294	20	0.106
	Clay Brick	1	100	
	Polystyrene	0.04	50	
	Exterior plaster	0.529	20	
Roof	Clay tile	1	25	0.190
	Glass wall roll	0.04	200	
	Roofing felt	0.19	5	
Floor	Ceramic tile	1.1075	8	0.108
	Cement screed	0.6578	22	
	Polystyrene	0.04	0	
	Concrete slab	1.7953	100	
Partition wall	Interior plaster	0.5294	20	2.296
	Clay Brick	1	100	
	Exterior plaster	0.529	20	

There are 3 things that can be concluded from Figure 7-2:

1. The first thing that can be seen in Figure 7-2 is the effect of roof insulation on the building's cooling demand. The model without roof insulation in the Passivhaus building model consumed almost three times the energy compared to other combinations of building material scenarios. By adding the roof insulation into the building model, the cooling energy will be significantly reduced.
2. The second thing that arose was the effect of floor insulation on the Passivhaus building. The cooling demand in Figure 7-2 was dropped if the Passivhaus building model was not using insulation in the floor.
3. There cooling energy amount from the different scenario of wall insulation thickness was only increase slightly when the wall thickness increase. From Figure 7-2 can be understood that wall insulation was important on reducing cooling energy but increasing the wall insulation thickness does not give the better performance to the building.

The study on the different types of windows glass was also made in this PHPP software. The optimum construction configuration from the previous analysis was used, that is: 50mm wall Insulation, 200mm roof Insulation and without floor insulation. With the applied construction setting, different glass thicknesses were used in the PHPP software and the cooling demand from the selected glass thickness then compared. The energy comparison of this scenario can be seen in Table 7-2. This table were made energy demand comparison from different windows glass and frames by using PHPP software. From the graph can be recognize that double and triple glass type does not make much different on the cooling energy demand. The possible reason for this result is the window opening is facing North and South, and the high-altitude sun does not contribute much in terms of direct solar heat gain.

Table 7-2 Comparison table of energy demand in the Passivhaus model with different windows glass and frames (The building model wall insulation was 50mm, the roof insulation was 200mm, and without floor insulation).

Glass thickness (mm)	U-value		Cooling demand kWh/(m ² a)
	Glazing	Frames	
Single glass	5.8	2.5	133
Double low-e glazing	1.3	0.75	129
Triple glass	0.7	0.59	128

Table 7-3 Monthly weather data from Meteoronorm for PHPP

Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating load		Cooling load	
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Weather 1	Weather 2
Jakarta epw	Latitude [°]	-6.1	Longitude [°]	107	Height a.s.l. (m)	9	Daily temperature variation summer (K)		7.3							
Temperature outdoor	26.4	26.2	26.7	27	27	26.7	26.5	26.6	27	27.3	27	26.5	25.6	25.9	27.1	29.2
North	40	41	52	78	105	111	109	102	68	53	52	47	71	36	191	78
East	68	62	79	86	85	76	78	89	94	86	93	74	87	40	166	181
South	65	53	47	45	45	43	45	49	48	61	89	79	71	39	76	181
West	59	64	82	80	82	79	81	91	87	84	90	72	83	38	162	175
Global	112	114	143	146	148	141	145	168	163	158	172	132	150	70	286	307
Dewpoint	23.1	23.2	23.2	23.5	23.3	22.6	22.2	21.6	21.9	22.6	22.9	23			21.1	21.3
Sky temperature	19.5	19.2	18.7	18.6	17.9	17.1	17.4	16.5	17	18.3	17.7	18.9				

Note: Heating loads developed together with Günther Gantioler/Bernhard Oberrauch (www.tbz.bz); cooling loads developed together with Passivhaus Institut (www.passiv.de).

Source: Meteoronorm version 7.2.4.31876



Figure 7-2 cooling energy demand comparison graph based on materials u-value.

From the PHPP software analysis it can be concluded that it is important to have roof insulation on the Passivhaus building in a tropical climate. Conversely, housing built in a hot and humid climate might not require any floor insulation. Introducing floor insulation in the Passivhaus building model indicated more cooling energy demand. A more detailed analysis was done when the Passivhaus standard was applied in the case study building model in the IES VE software and compared the energy demand with the Passivhaus building without floor insulation. Wall insulation was important in the tropical country, but additional insulation does not improve the building performance. The same situation was happening with glazing type, where double and triple glazing indicated the relatively same performance in terms of cooling energy demand.

7.3 Applying Passivhaus into DesignBuilder validated model

The Passivhaus Standard criteria described in chapter 3 were used to build the Passivhaus model in DesignBuilder software. To create the Passivhaus model in DesignBuilder, the validated model building element from section 6.2 was modified by applying the Passivhaus building standard. The maximum airtightness 0.6 ach^{-1} that is required in the Passivhaus Standard was applied in the Passivhaus model. The building airtightness that complies with the Passivhaus requirement was achieved by applying insulation into the building material used in the real building.

The Passivhaus building constructional layers for building model in DesignBuilder are listed in Table 7-4. This insulation was placed in all external walls and party wall on the internal side, to avoid air leakages and thermal bridges in the building model. The insulation thickness was gained from previously made the PHPP study. Building orientation in a tropical climate is important, to limit the solar gain from the sun into the building. Since the monitored house was oriented North-South, there is no modification on the building orientation needed. The windows glass was changed into double glazing to suit the Passivhaus standard, and a window blind component on the window properties was maintained as protection to the direct solar gain into the window.

To study the performance of the Passivhaus strategies in a hot and humid climate, comparisons were made between the 'original building element model' (OB model) and the applied Passivhaus building model (PB model). The OB model was used to represent the

typical built building in Jakarta Metropolitan Region, and PB model to represent the building with Passivhaus applications on the typical building in Jakarta Metropolitan Region. The simulation was run in the two-building model built in DesignBuilder. The OB model was using the validated model in DesignBuilder, and the PB model was using the validated DesignBuilder model with the applied Passivhaus concepts. The construction setting that was used in the OB model is listed in Appendix H with the activity schedule listed in Appendix I. The construction setting that was used in the PB model is listed in Appendix J with the activity schedule listed in Appendix K.

Table 7-4 Passivhaus building elements in DesignBuilder

Building Element	Constructional layers	Reference U-value (W/m ² K)
External walls	25mm thick cement plaster + 100mm thick clay brick + 50mm XPS Extruded Polystyrene + 25mm thick cement plaster	0.627
Party walls	25mm thick cement plaster + 100mm thick clay brick + 50mm XPS Extruded Polystyrene + 25mm thick cement plaster	0.590
Internal wall	25mm thick cement plaster + 100mm thick clay brick + 100mm XPS Extruded Polystyrene + 25 mm thick cement plaster	2.894
Floor	8mm thick ceramic tile + 22mm thick cement screed + 100mm thick concrete slab + 150mm Urea Formaldehyde Foam + soil layer	0.247
Window	6 mm thick double layer glass. (total solar transmission (SHGC) = 0.568)	1.761
Ceiling	6 mm thick gypsum board	3.125
Pitched roof	25mm thick roof tile + 25mm thick timber batten + 200mm MW Glass Wool (rolls) + 5mm thick roofing felt	0.193

The first analysis was made by creating cooling for both scenarios with the same air-conditioning (AC) system that supplied cooling for the living room, master bedroom, and children's bedroom. For the simulation, the AC setting was made so the room air temperature was on the comfort temperature in Jakarta, which was described in the previous chapter as ranging between 24°C to 27.8°C. The second analysis was done by applying dehumidification to lower the relative humidity in both scenarios. In DesignBuilder, the HVAC template that used AC and/or dehumidifier was chosen and applied to both scenarios.

7.3.1 Original building element model vs Passivhaus model with air-conditioned (AC) system.

In this chapter, both scenario building models, which are the OB model and the PB model, will be applied with the same HVAC template system before the simulation was run. The DesignBuilder HVAC template chosen to be applied in both models was “Unitary Heat Cool” template (Figure 7-3). This HVAC configuration template was using AHU with Direct-expansion (DX) cooling coil without heating, so airflow control modified for cooling only in the AHU operation. This DesignBuilder HVAC system was chosen to represent the air-conditioned (AC) used in the building model. Heat recovery in the HVAC template was to simulate the heat exchanger used in Passivhaus standard. In this simulation, the changes on the HVAC template were made on the Setpoint Manager which using temperature control variable that set to ensure the room temperature will be always on the comfort level in Jakarta.

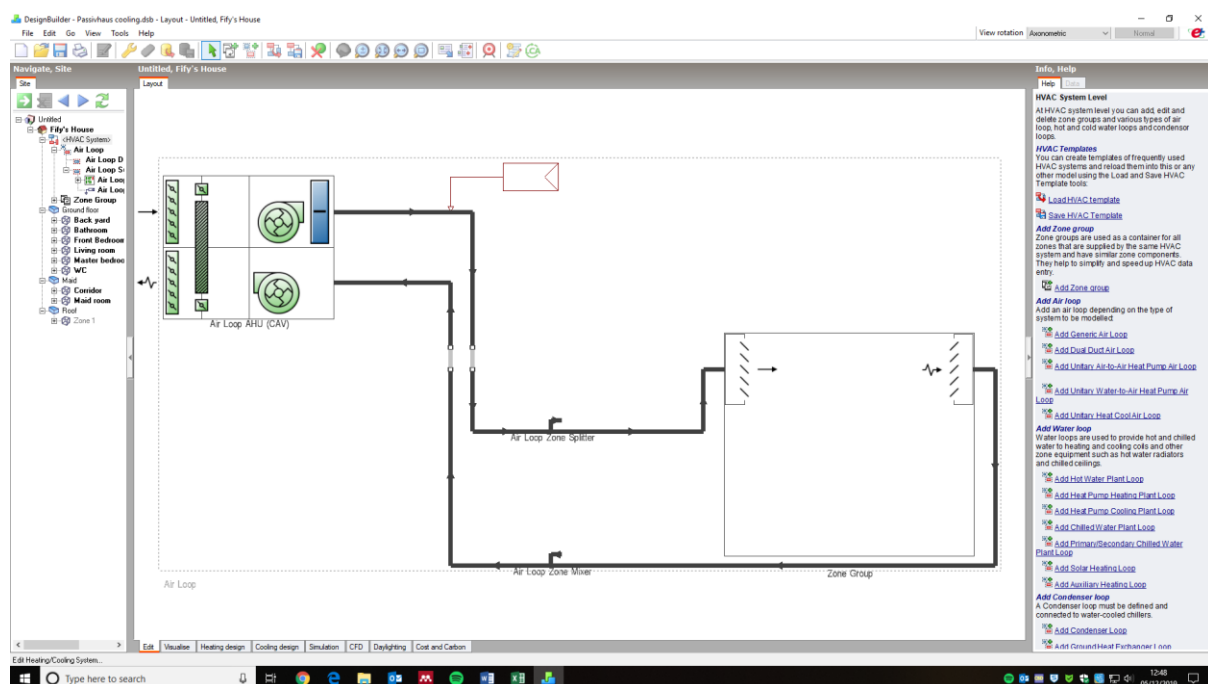


Figure 7-3 Unitary Heat Cool template preview in DesignBuilder software.

With all the setting made and applying the AC system into the building, the simulation on OB building model and PB building scenario was then run. The relation between air temperature and relative humidity for OB building model and PB building model that using AC as HVAC system were shown in the Figure 7-4. The highlighted area was the thermal comfort range in Jakarta – Indonesia, green for temperature and blue for relative humidity. From the distribution map, it is clearly seen that the air temperature for the building model with AC

system was mostly in the thermal comfort range. The air temperature for the building model was monitored only a few times outside the thermal comfort. But as can be seen in the graph that the relative humidity for both building model was monitored above the comfort range. Figure 7-5 indicates that the relative humidity for both model, OB model and PB model, was almost all the time above 65% with AC system.

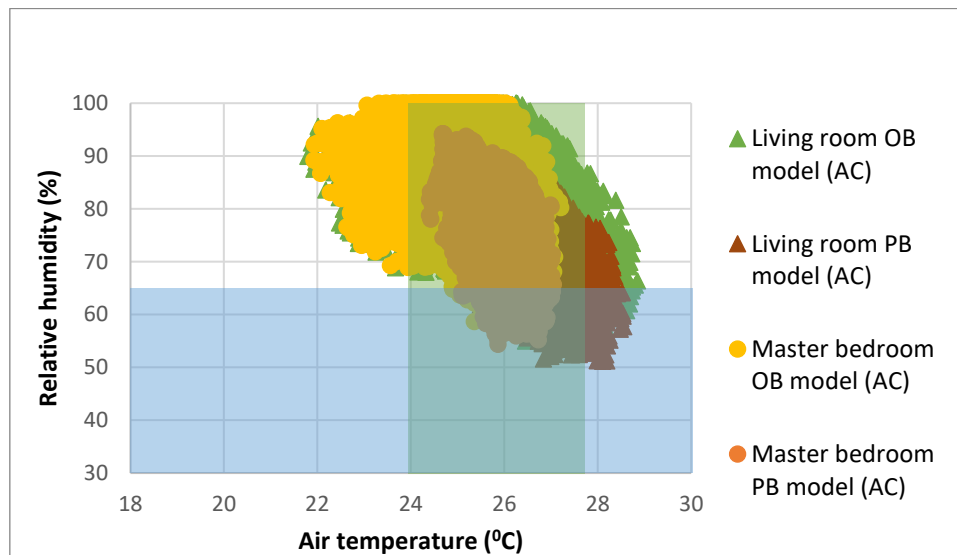


Figure 7-4 The relative humidity and air temperature distribution for one-year period in the building model using air conditioning.

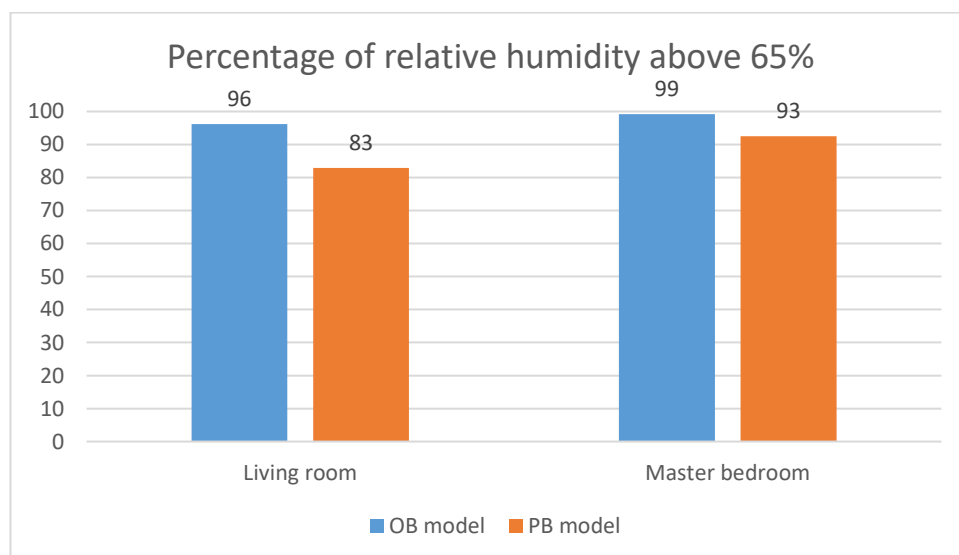


Figure 7-5 Percentage of relative humidity above 65%.

The one-year period simulation result graph for OB model and PB model is shown in Figure 7-6 and Figure 7-7. The graph indicates the hourly air temperature in the living room and master bedroom for a one-year period. From the graph it can be seen that generally the air

temperature from the PB model's scenario that was using AC system was in the thermal comfort range. By using AC for the cooling system, the room temperature in PB model can be maintained stable in the comfort range for the whole year. On the other hand, with the AC system in the OB model, the rooms temperature was a few times below the comfort range. The low temperature was carried out in attempt to reduce the building relative humidity, since the building was only using AC as the HVAC system.

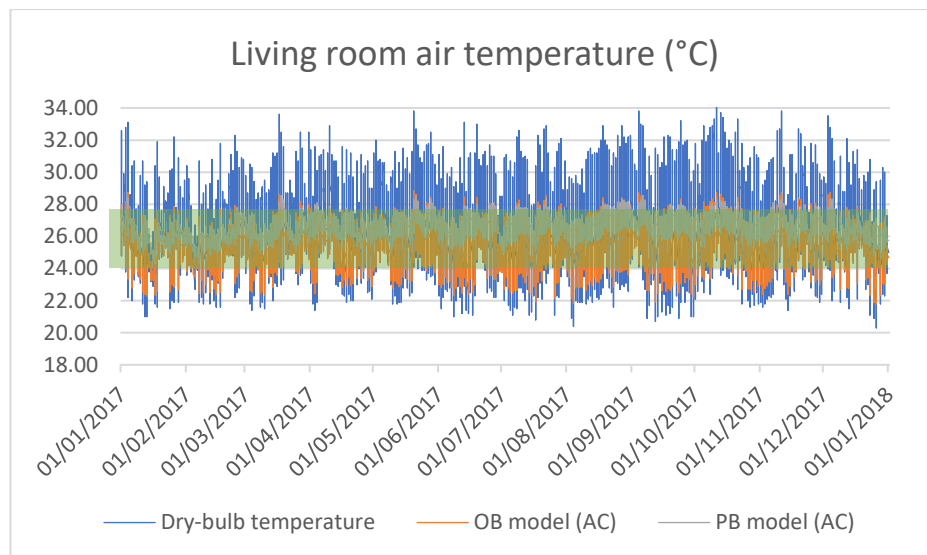


Figure 7-6 Living room air temperature comparison between OB model and PB model, with AC system.

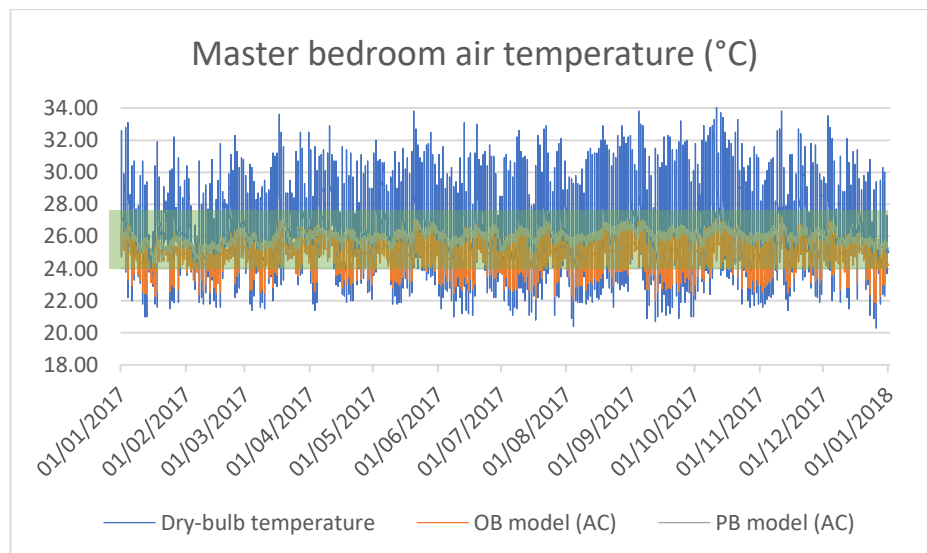


Figure 7-7 Master bedroom air temperature comparison between OB model and PB model, with AC system.

The hourly relative humidity simulation results for OB model and PB model in this scenario are shown in Figure 7-8 and Figure 7-9. This graph indicates that the relative humidities for both scenarios were following the external relative humidity, both in the living room and

master bedroom. The relative humidity in the PB model was indicated lower than the OB model, but the PB relative humidity was observed still above the comfort range for most of the time. Figure 7-10 and Figure 7-11 show the relative humidity comparison in the living room and master bedroom for 29 October until 5 November. This graph clearly indicates that the relative humidity for OB model was following the external relative humidity, with the relative humidity for the PB model fluctuating below 80% relative humidity for the whole time.

With this analysis can be seen that the AC system on the “original building element” (OB model) and the Passivhaus building model (PB model) can lower the room air temperature to be in the thermal comfort range but were not able to reduce the internal relative humidity. The AC was seen able to reduce the relative humidity slightly for the OB model, and the AC in the PB model was able to lower the relative humidity quite significant. But the relative humidity of the PB model was still above the comfort level, and the AC system cannot push the internal humidity into the comfort range. The energy consumption with the built model will be discussed in the next section (Section 7.3.3).

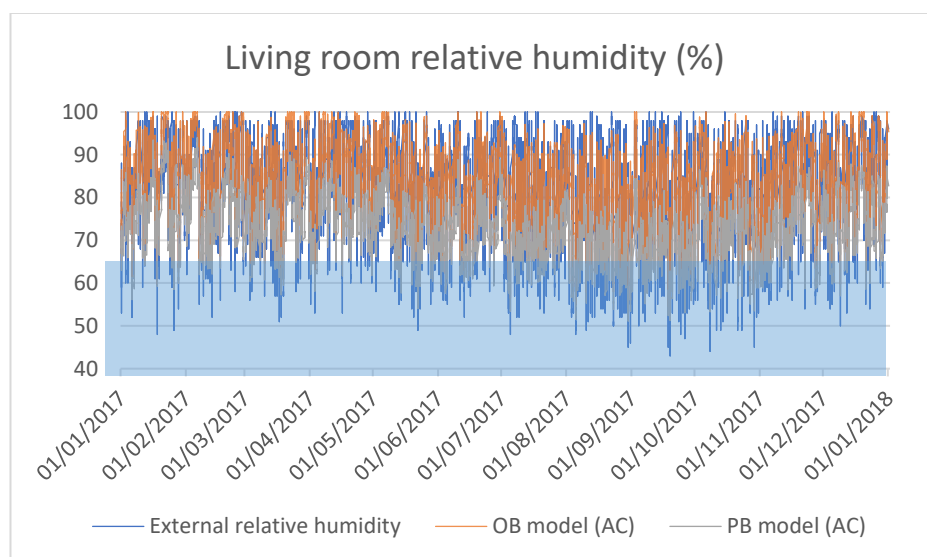


Figure 7-8 Living room relative humidity comparison between OB model and PB model, with AC system.

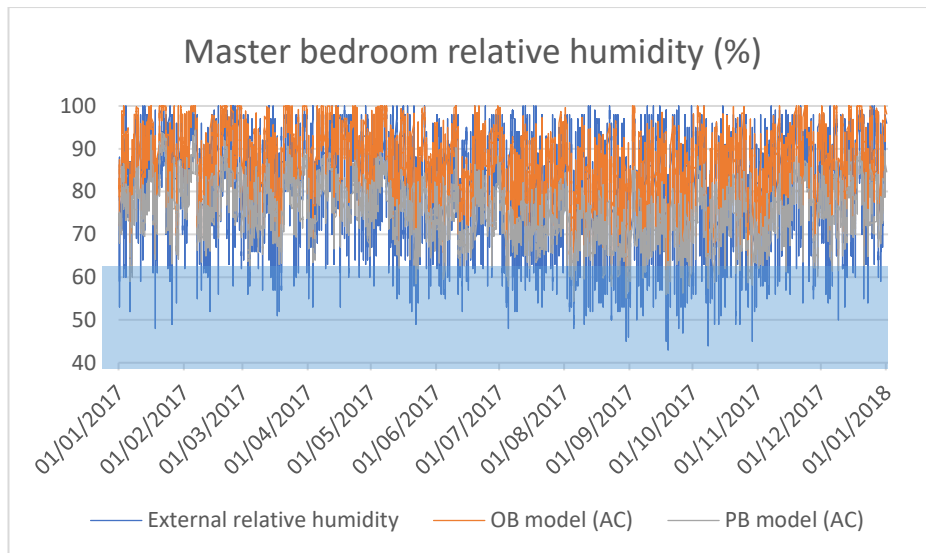


Figure 7-9 Master bedroom relative humidity comparison between OB model and PB model, with AC system.

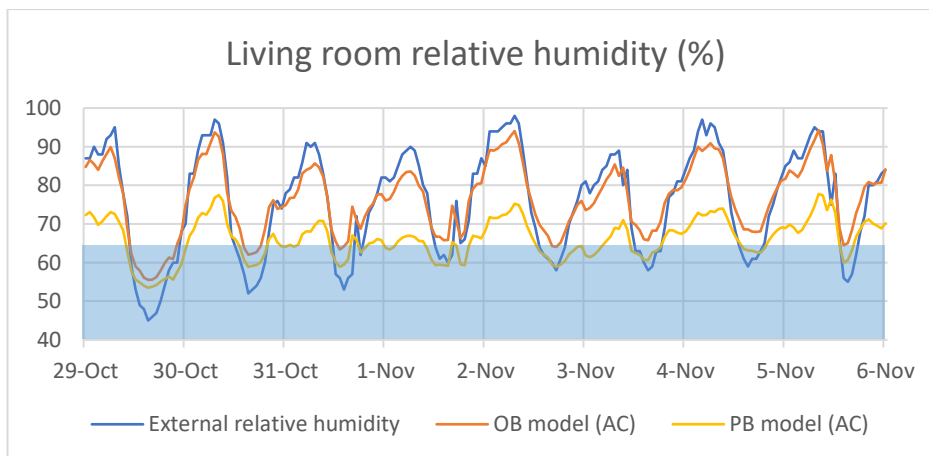


Figure 7-10 Living room relative humidity comparison from 29 October – 5 November between OB model and PB model, with AC system.

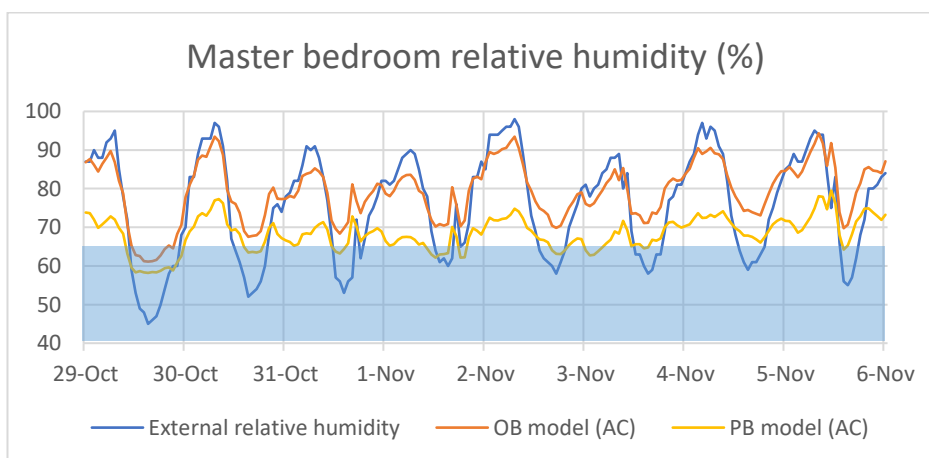


Figure 7-11 Master bedroom relative humidity comparison from 29 October – 5 November between OB model and PB model, with AC system.

7.3.2 Using air conditioning (AC) and dehumidifier

The first analysis indicated that the relative humidity in the living room and master bedroom cannot be lowered if the building model was only using AC as a HVAC system. So, in this section the experiment was done by applying a dehumidifier to lower the room relative humidity into a comfort level in addition to air conditioning. The AC and dehumidifier HVAC system were applied into the OB model and PB model to study the impact of the dehumidifier in the built building model. The DesignBuilder HVAC template used in the simulation was using “VAV reheat, DX cooling with dehumidification” (Figure 7-12). The system was using AHU with Direct-expansion (DX) cooling coil with humidistat control to control the room humidity. There were two Setpoint Managers that were used as the controller, one for the air temperature controller and the other one for relative humidity controller. With this two Setpoint Manager, the HVAC was set to bring comfort to the rooms in term of relative humidity and air temperature.

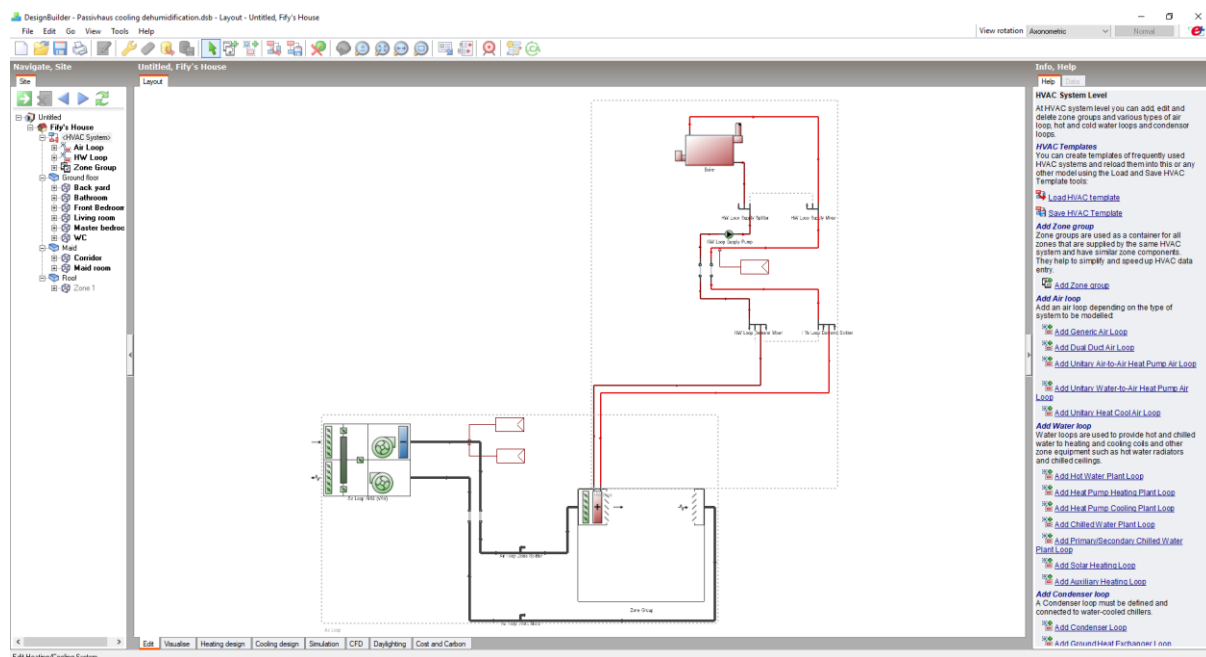


Figure 7-12 VAV reheat, DX cooling with dehumidification HVAC template preview in IES VE software.

By running simulation in this HVAC template, the distribution of air temperature against relative humidity results was made and is shown in Figure 7-13. The thermal comfort range was shown with the green area, and the relative humidity was indicated by the blue highlighted area. The graph specifies that the HVAC system using AC and dehumidifier was pushing the room air temperature to be lower than thermal comfort range. The graph was

indicating the relative humidity OB model was above the PB model relative humidity that was maintained below 80%.

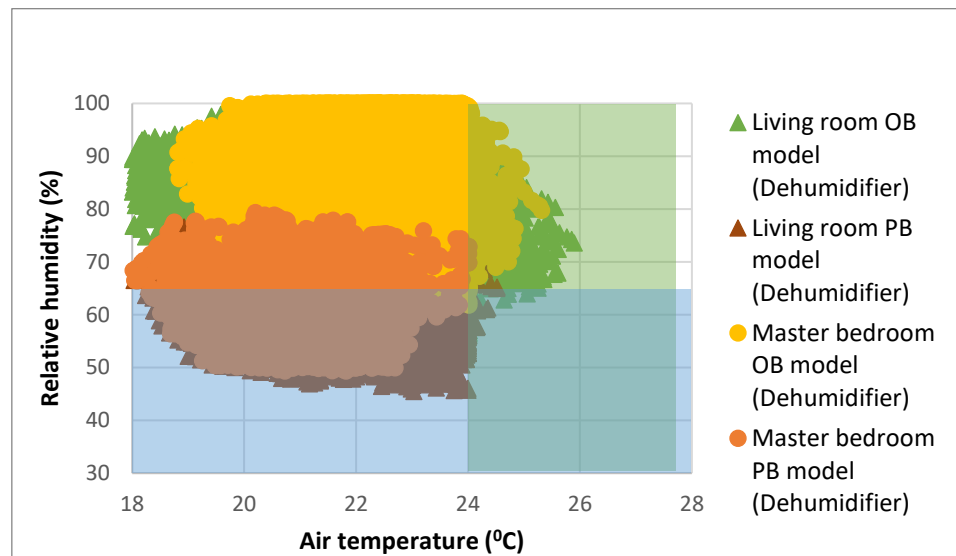


Figure 7-13 The relative humidity and air temperature distribution for one-year period in the building model with air conditioning + dehumidifier system.

The simulation results in the living room and master bedroom in Figure 7-14 and Figure 7-15 show the air temperature for both building scenario were below the thermal comfort range for all the time. The graph is also indicating that the PB model had a more stable air temperature than the OB model. The OB model fluctuated from 18°C to 26°C, while PB model was fluctuated from 19°C to 24°C. The analysis for this situation was described more with the graph below.

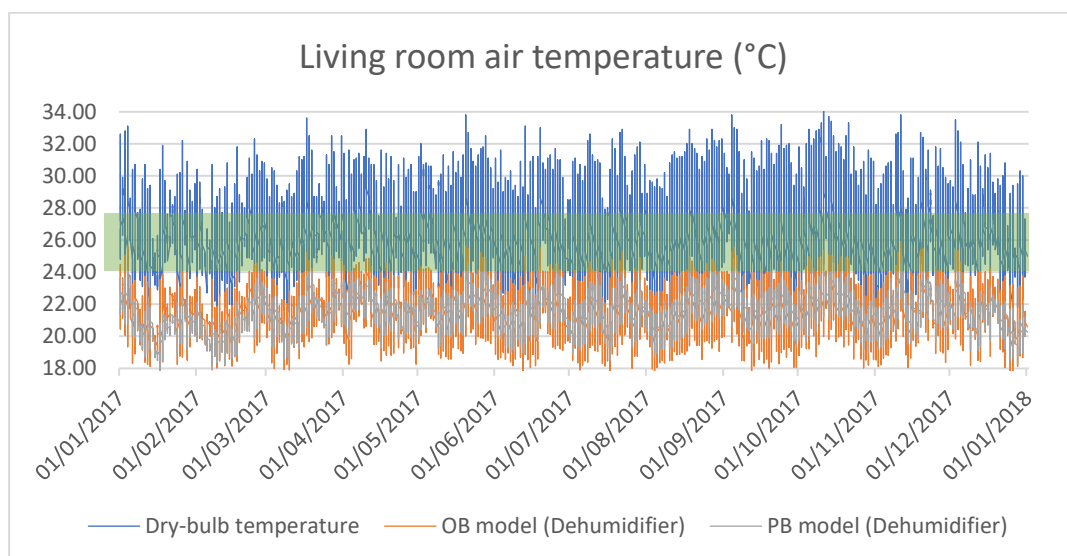


Figure 7-14 Living room air temperature comparison between OB model and PB model, with AC + dehumidifier system.

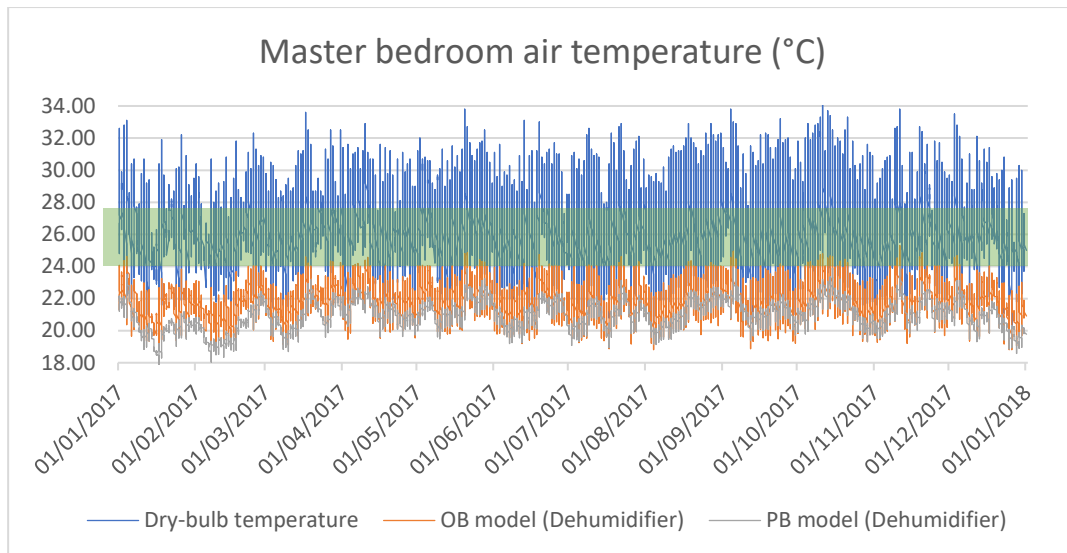


Figure 7-15 Master bedroom air temperature comparison between OB model and PB model, with AC + dehumidifier system.

The relative humidity for the one-year period in Figure 7-16 and Figure 7-17 demonstrated how the OB model's relative humidity fluctuated close to the outdoor relative humidity. The graph also highlighted that almost all the time the relative humidity of OB model was above the comfort range. On the other hand, the PB model was, for most of the time, positioned within the comfort range.

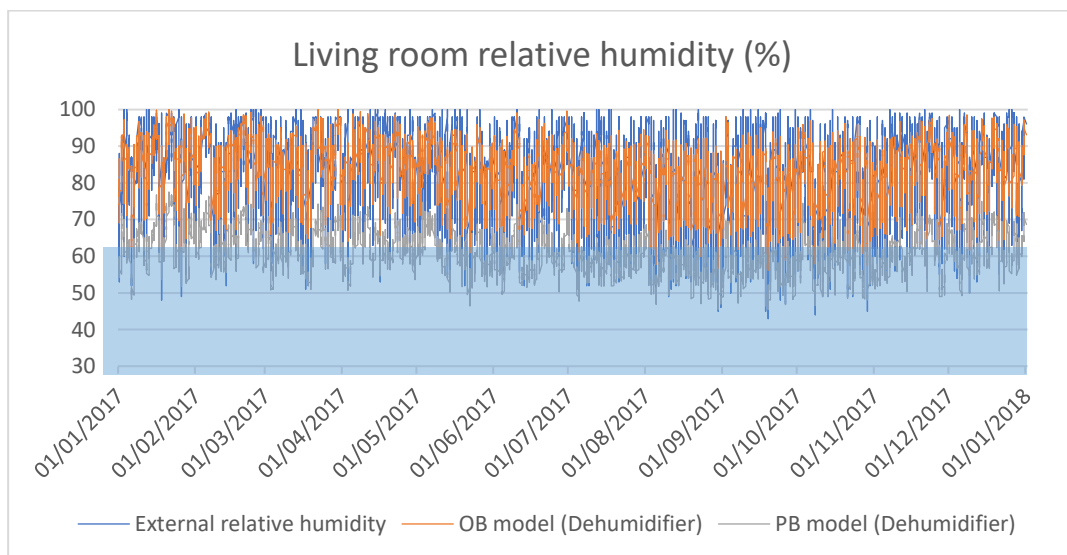


Figure 7-16 Living room relative humidity comparison between OB model and PB model, with AC + dehumidifier system.

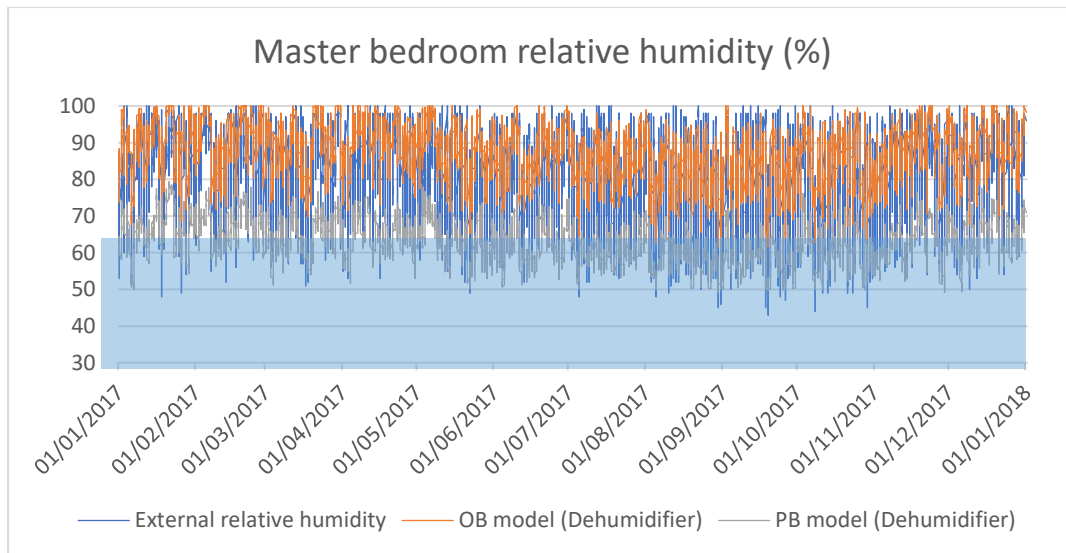


Figure 7-17 Master bedroom relative humidity comparison between OB model and PB model, with AC + dehumidifier system.

The zoom in relative humidity graphs in Figure 7-18 and Figure 7-19 show the rooms' relative humidities from 29 October until 5 November, confirming that the OB model relative humidity that following the outdoor relative humidity. On the other hand, this zoom in relative humidity shows that PB model relative humidity was keeping below 60%, even though in the yearly graph it was indicated that there were some periods when the relative humidity was above 60%. The PB model relative humidity was monitored as quite stable during the selected period.

Figure 7-20 suggests that the period of relative humidity was above 65% relative humidity for both models. This graph clearly indicates that the OB model relative humidity was all the time above 65% relative humidity and only 30% of PB model relative humidity was still above 65% relative humidity. The additional dehumidifier on the HVAC system was not able to reduce the room relative humidity for OB model, but was able reduce the relative humidity significantly on the PB model.

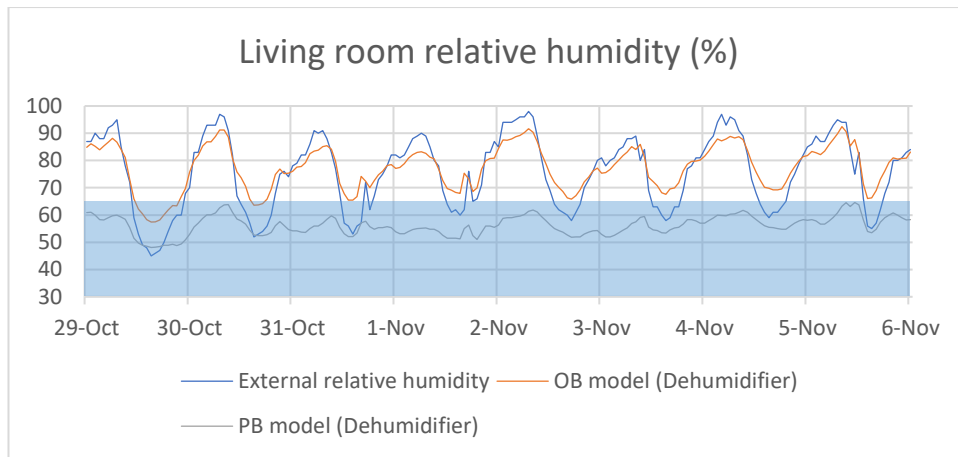


Figure 7-18 Living room relative humidity comparison from 29 October – 5 November between OB model and PB model, with AC + dehumidifier system.

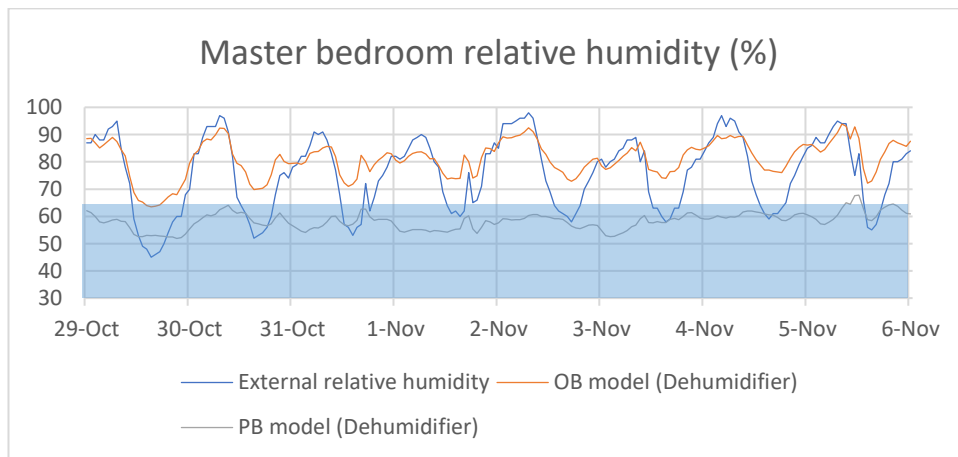


Figure 7-19 Master bedroom relative humidity comparison from 29 October – 5 November between OB model and PB model, with AC + dehumidifier system.

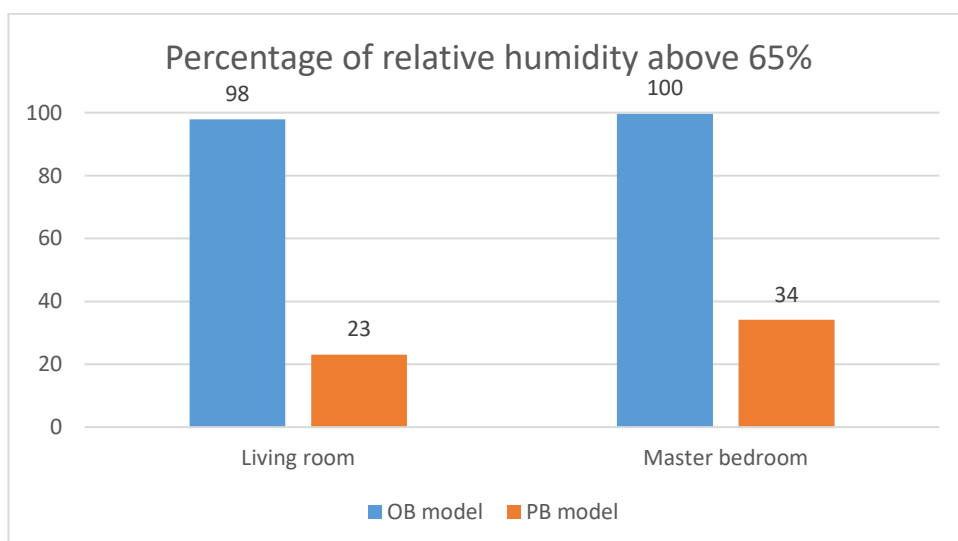


Figure 7-20 Percentage of relative humidity above 65%.

7.3.3 Energy demand comparison

Different HVAC systems in DesignBuilder were chosen to compare the 'original building element model' (OB model) and the applied Passivhaus building model (PB model). The schedule for this HVAC is listed in Appendix I and Appendix K. The performance of the building model built in DesignBuilder was discussed in the previous subchapter. There were two HVAC system that was used in this comparison, the first using type "Unitary Heat Cool" template that represent the air conditioning system, and the second was using "VAV reheat, DX cooling with dehumidification" template that represent the dehumidifier and air conditioning system.

The analysis in the previous subchapter was indicating that applying the HVAC system template in the building model was bringing the air temperature to be in the thermal comfort range for both models in both scenarios, with only a few times being lower than thermal comfort range for OB model. The relative humidity for the HVAC system that represented AC indicated high relative humidity for all the time in both building models, while for HVAC system that represented AC and dehumidifier, it was only the OB model with high humidity. The PB model's relative humidity was detected only 30% of time above 65% relative humidity yearly with the additional dehumidifier. The analysis found that the additional dehumidification into the building HVAC system was able to improve the building air temperature and relative humidity for PB model. To look at the effectiveness of this HVAC system and to look at the Passivhaus performance in the hot and humid climate, a energy comparison was made (Figure 7-21).

The AC system scenario on both models, OB model and PB model, indicated it had lower energy use than the AC with dehumidifier scenario. The energy comparison in Figure 7-21 indicates that OB model using AC system only consumed 2MWh/year for cooling energy. If the OB model used the dehumidifier the energy use would almost reach 12MWh/ year, but the internal relative humidity was still high. From the analysis in section 7.3.2 can be seen that the air temperature in the PB model with AC + dehumidifier was higher than the air temperature when the PB model using AC system only. The "VAV reheat, DX cooling with dehumidification" template that used in DesignBuilder was trying to lower the air temperature to be able to reduce the internal relative humidity, this consumed more energy for cooling. But when the room air temperature was push until 18°C internally, the system was still not able to lower the relative humidity for OB model. For PB model, the additional

dehumidifier was able to reduce the relative humidity but made the air temperature lower than thermal comfort range. The energy used for PB model that using dehumidifier was lower than the OB model in the same scenario. So, with lower energy, the PB model was performing better than the OB model.

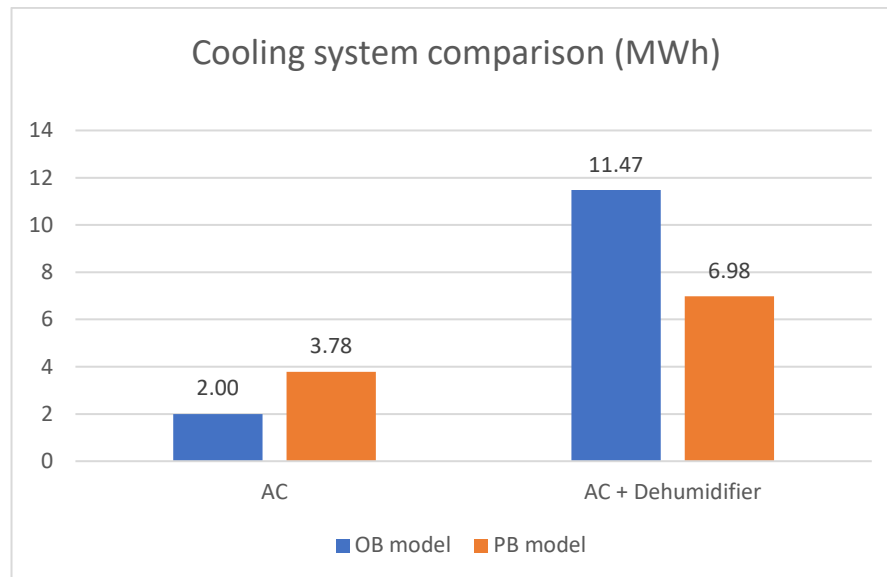


Figure 7-21 Yearly space cooling energy comparison between OB model and PB model.

The graph indicated that the applied Passivhaus standard into a building in a tropical climate was able to perform better and at the same time was able to reduce the cooling energy compared with the model with the original building elements. The analysis found that by changing the Setpoint Manager in the HVAC system with dehumidifier in DesignBuilder it was not able to fully reduce the internal relative humidity completely for the PB model. The HVAC system even was also not able to reduce the relative humidity at all in the OB model. So, in the next section, the analysis continues by using IES VE to make a full comparison of OB model and PB model performance under AC and AC with dehumidifier system.

7.4 Applying Passivhaus into IES VE validated model

The same validation process as the building model in DesignBuilder was made in IES VE software. The Passivhaus criteria explained in Chapter 3 were used to build the Passivhaus model in IES VE software. The validated model building element from section 6.3 was modified to build the Passivhaus building model that was applied with Passivhaus requirement. To create an airtight building that complied with the Passivhaus requirement, the building material used in the real building had insulation added with insulation. The

Passivhaus building constructional layers are listed in Table 7-5. This insulation was placed in all external walls and party wall on the internal side, to avoid air leakages and thermal bridges in the building model. The insulation thickness was that used previously in the PHPP study. Building orientation in tropical climate is important, to limit the solar gain from the sun into the building. Since the monitored house was oriented North-South, there is no modification on the building orientation needed. The windows were changed into double glazing to suit the Passivhaus standard, and shading on the window was maintained as protection to the direct solar gain through the windows. The setting for building airtightness was also made 0.6 ach^{-1} , to follow the maximum building airtightness required by Passivhaus standard.

Table 7-5 Passivhaus building elements in IES VE

Building Element	Constructional layers	U- Value ($\text{W/m}^2\text{K}$)
External walls	25 mm thick cement plaster + 100 mm thick clay brick + 100 mm XPS Extruded Polystyrene + 25 mm thick cement plaster	0.158
internal walls	25 mm thick cement plaster + 100 mm thick clay brick + 25 mm thick cement plaster	2.296
Party wall	25 mm thick cement plaster + 100 mm thick clay brick + 100 mm XPS Extruded Polystyrene + 25 mm thick cement plaster	0.158
Floor	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + Urea Formaldehyde Foam + soil layer	0.232
Window	6 mm thick double layer glass. (g-value = 0.7062)	3.170
Ceiling	6 mm thick gypsum board.	3.125
Pitched roof	20 mm thick roof tile + 25 mm thick timber batten + 200 mm MW Glass Wool (rolls) + 5 mm Roofing felt.	0.121

To study the performance of the Passivhaus strategies in a hot and humid climate, the comparisons were made between the 'original building element model' (OB model) and the applied Passivhaus building model (PB model). The OB model was using the validated model in IES VE, and the PB model was using the validated IES VE model with the applied Passivhaus concept. The OB model was used to represent the typical built building in Jakarta Metropolitan Region, and the PB model to represent the building with Passivhaus applications in the typical building in Jakarta Metropolitan Region. The simulation was run in the two-building model built in IES VE. The OB model was using the validated model in IES VE, and the

PB model was using the validated IES VE model with applied Passivhaus concept. The construction setting that was used in the OB model is listed in Appendix L, and the construction setting that was used in the PB model is listed in Appendix M. The activity schedule for OB model and PB model were the same, and it is listed in Appendix O.

The first analysis was made by creating cooling for both scenarios with the same air-conditioning (AC) system that supplied cooling for the living room, master bedroom, and children's bedroom. For the simulation, the AC temperature set point was adjusted to be able to achieve the thermal comfort range in Jakarta. The next analysis was done by adding the dehumidifier to the building model, to lower the relative humidity in both scenarios. In the IES VE, the HVAC template that used AC and AC + dehumidifier was chosen and applied to both building models.

7.4.1 Original building element model vs Passivhaus model with air-conditioned (AC) system

In this part the experiment was continued by applying the same HVAC system template into both scenario building models which are OB model and PB model. The IES VE HVAC template chosen to be applied in to both models were type 05d - "Multizone Variable Air Volume (VAV) Reheat System" (Figure 7-22). This HVAC configuration template was using AHU with Direct-expansion (DX) cooling coil without heating, so airflow control modified for cooling only in the VAV operation. The HVAC system in IES VE was chosen to represent the air-conditioned (AC) used in the building model. Energy recovery heat exchanger in the HVAC template was to simulate the heat exchanger used in Passivhaus standard. All default system features in the HVAC template were either optional or can be modified and re-configured in ApacheHVAC via the system parameters dialog, airside schematics, and plant equipment dialogs. In this simulation, the changes on the HVAC template were made on the system occupancy schedule profile which using the case study occupied hours operation, and the setback temperature to suit the need of fulfill the thermal comfort range. The temperature setpoint was made to ensure the room temperature in the building model was in the thermal comfort range.

After all the Passivhaus standard and the AC system were applied in the building model, the simulation on both building model scenarios were then run. The relation between air temperature and relative humidity for OB and PB building model using AC as the HVAC system are shown in Figure 7-23. From the distribution map, it is clearly seen that the air temperature

for PB model was in the thermal comfort range and the air temperature for the OB model was mostly below the thermal comfort range (the highlighted blue area). Similar to the condition with the air temperature, the building model relative humidity distribution was indicating that mostly the PB model relative humidity was in the comfort range but most of the OB model's relative humidity was above the comfort range. The graph also indicated that the relative humidity in the master bedroom for PB model was above 65% several times.

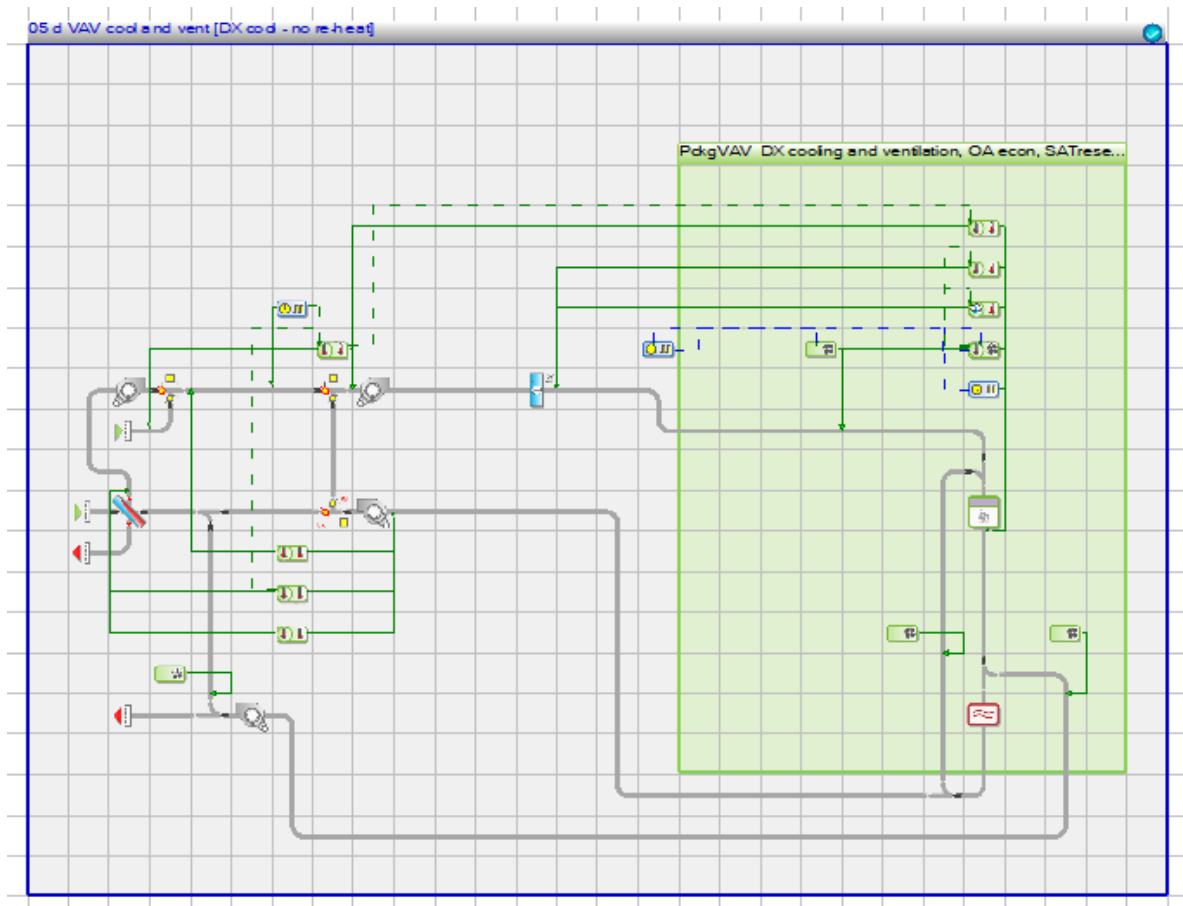


Figure 7-22 HVAC template type 05d - "Multizone Variable Air Volume (VAV) Reheat System" from IES VE HVAC.

To look in more detail on the building performance with AC system, the one-year period simulation result graphs for OB model and PB model air temperatures were made (Figure 7-24 Figure 7-25). The graph indicates the comparison of hourly air temperature in living room and master bedroom for one-year period. From the graph it can be seen that the air temperatures for OB model and PB model were always in the comfort range for the applied system. But with the applied setting, the relative humidity for the OB model was all the time higher than the comfort level, meanwhile for the OB model, the relative humidity can be maintained in

the comfort level zone. Figure 7-26 indicates that over 75% of occupied time, the room relative humidity was higher than comfort level.

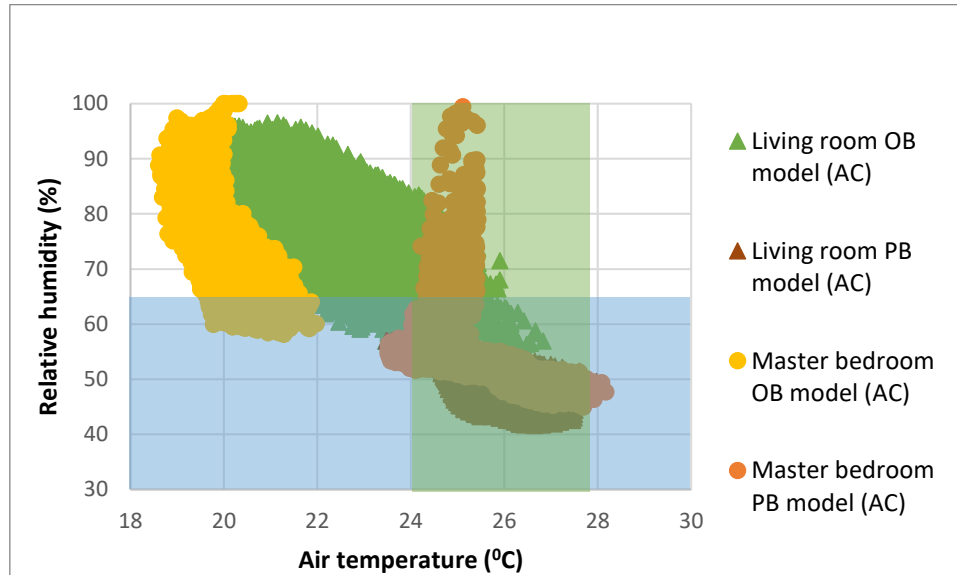


Figure 7-23 The relative humidity and air temperature distribution for one-year period in the building model with air conditioning.

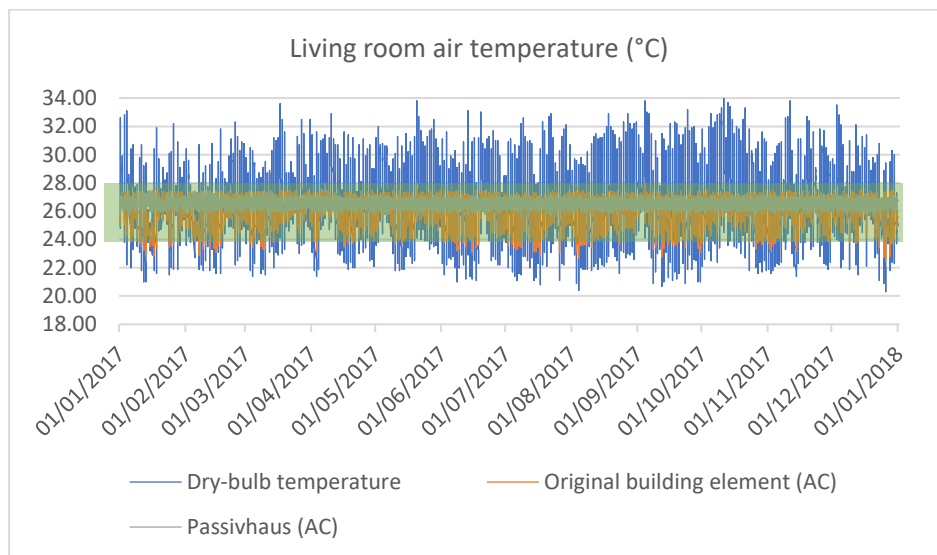


Figure 7-24 Living room air temperature comparison between OB model and PB model with AC system.

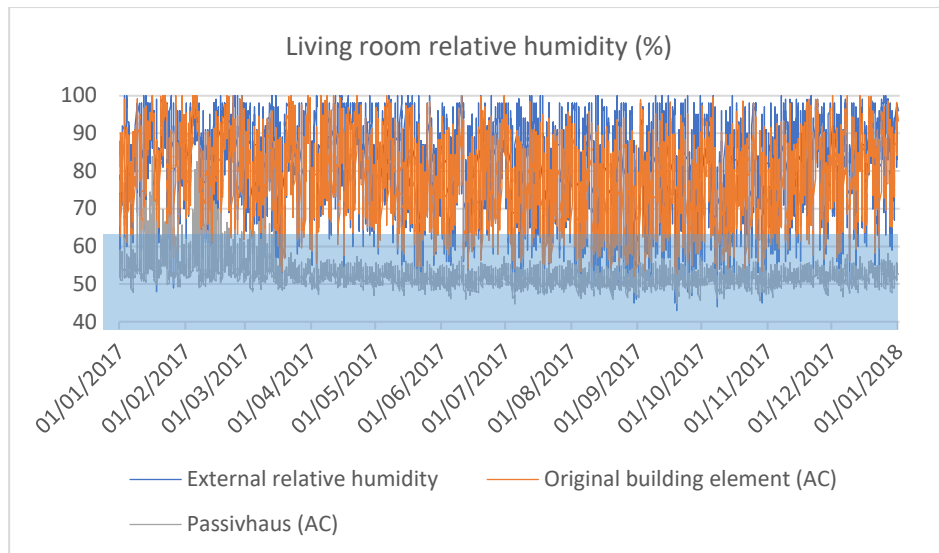


Figure 7-25 Living room relative humidity comparison between OB model and PB model with AC system.

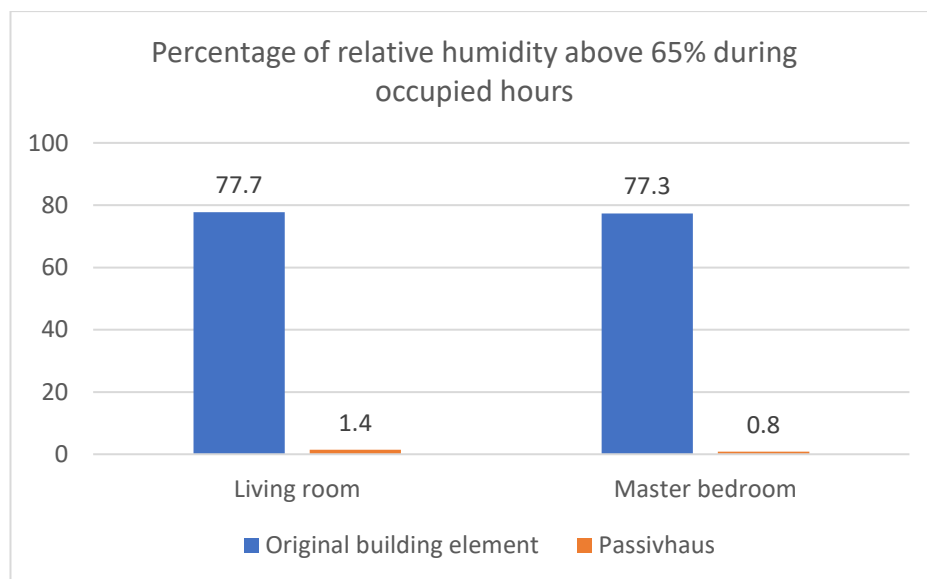


Figure 7-26 Percentage of relative humidity above 65% during occupied hours.

The possibility to lower the high relative humidity in the OB model by lowering the cooling set point was explored. From Figure 7-27 and Figure 7-28 it can be seen that generally the performance of the PB building model was mostly in the thermal comfort range, but with the HVAC system, the lower air temperature for OB model that was around 19°C - 25°C and was not able to push the room relative humidity below 60%.

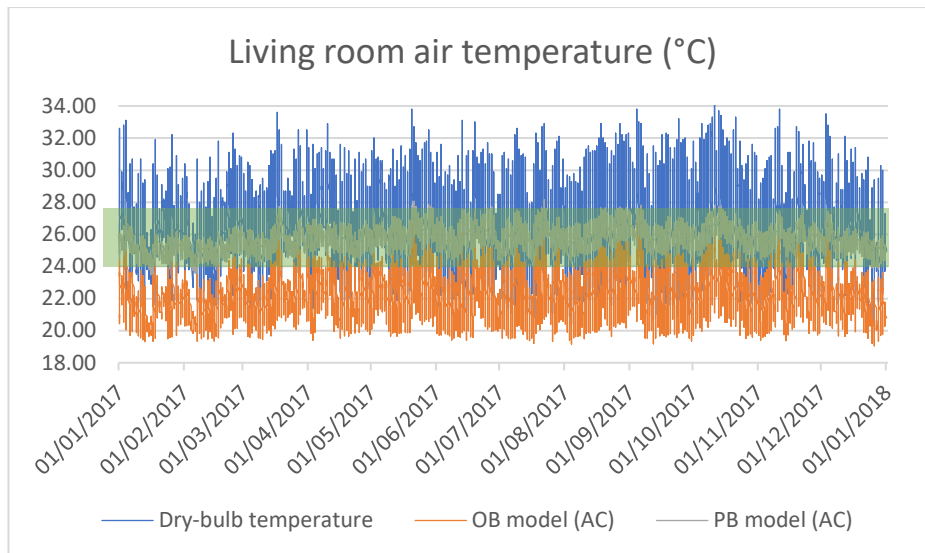


Figure 7-27 Living room air temperature comparison between OB model and PB model with AC system.

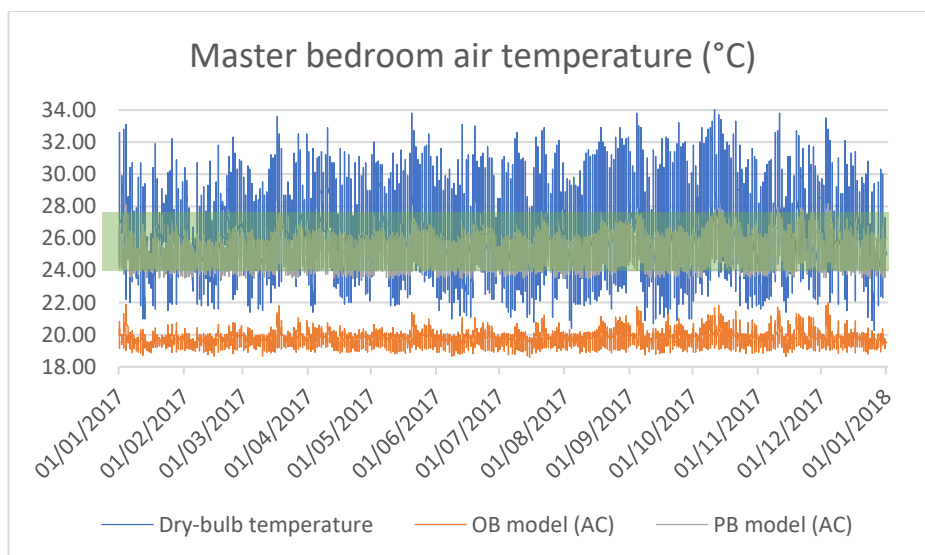


Figure 7-28 Master bedroom air temperature comparison between OB model and PB model with AC system.

The hourly relative humidity simulation results for OB model and PB model in this scenario are shown in Figure 7-29 and Figure 7-30 to look at the relative humidity in living room and master bedroom area with the AC system. For PB model, the relative humidity for the living room area is mostly below 60% for the whole year, but in the master bedroom there was still certain periods when the relative humidity was above 60%. The high relative humidity in the master bedroom was detected when the room was not occupied. Based on the analysis with

the IES VE software, during the occupied hours the room's relative humidity was always below 60%. This is because the HVAC system schedule in this scenario was based on activity schedule, so the HVAC system was turned on when the room was occupied.

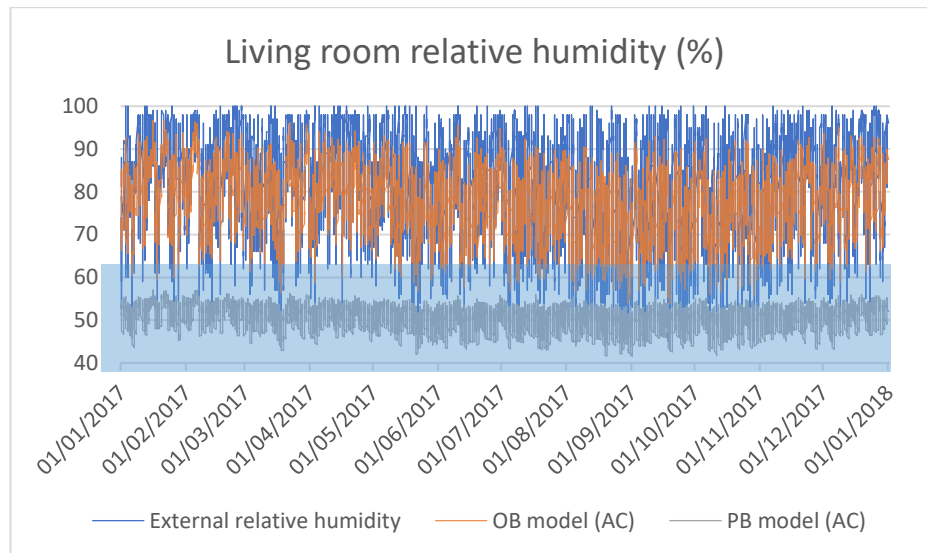


Figure 7-29 Living room relative humidity comparison between OB model and PB model with AC system.

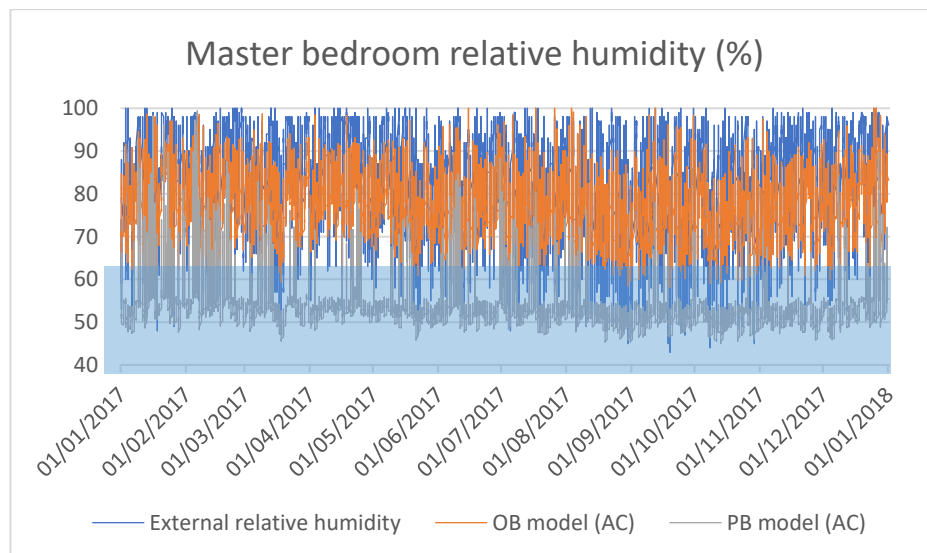


Figure 7-30 Master bedroom relative humidity comparison between OB model and PB model with AC system.

A different situation was happening with the OB model, where the AC system was still not able to bring the relative humidity into the comfort range. The internal relative humidity was

only slightly lower than external relative humidity with the applied AC system. The graphs in Figure 7-31 and Figure 7-32 show the relative humidity in the living room and master bedroom respectively from 29 October until 6 November, indicating that the living room and master bedroom relative humidities were stable at 50% - 60% for PB model but for the OB model the relative humidity was following the external relative humidity. The OB model's relative humidity was only lowered by 10% of the daily external temperature with the applied system.

In the master bedroom the relative humidity had a peak during 9.00 morning until around 12.00 noon, when the bedroom was not occupied. The relative humidity drops at around 12.00 noon mainly to follow the drop of outdoor temperature. The percentage of relative humidity above 65% during occupied hours is shown in Figure 7-33. The percentage of relative humidity above 65% for PB model was 0, that is mean during the occupied hours the relative humidity was always in the comfort level. With the applied AC system only was able to maintain the internal air temperature to be at the thermal comfort range and at the same time creating the room relative humidity in the comfort range. Whereas for the OB model, the relative humidity above comfort level during occupied hours was almost 100%. That is mean the room's relative humidity was almost all the time above the comfort level.

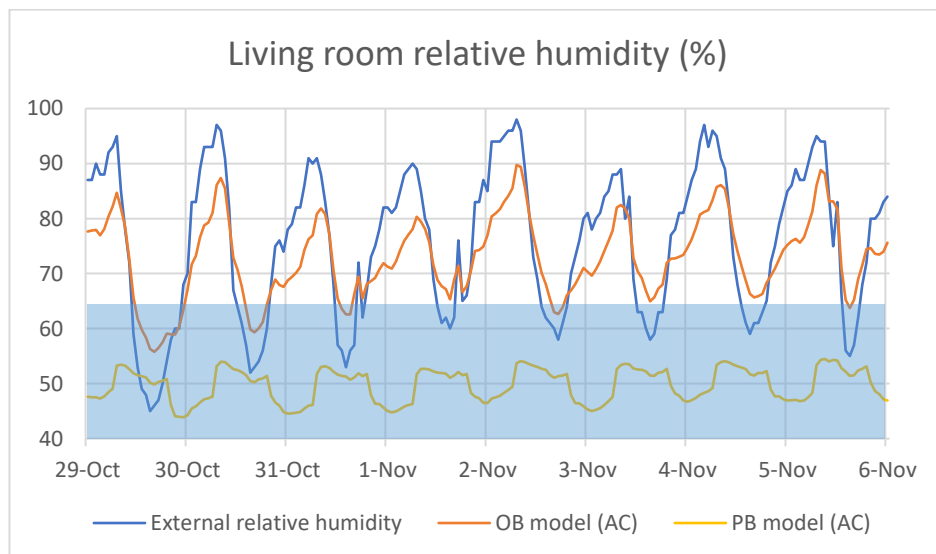


Figure 7-31 Living room relative humidity comparison between OB model and PB model with AC system from 29 October until 6 November.

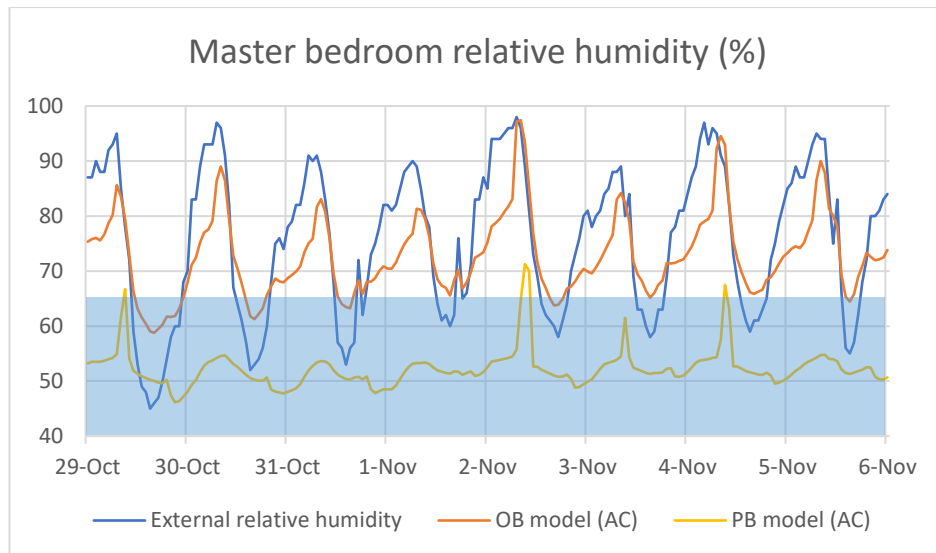


Figure 7-32 Master bedroom relative humidity comparison between OB model and PB model with AC system from 29 October until 6 November.

With this analysis it can be seen that the AC system in the “original building element” (OB model) and the Passivhaus building model (PB model) can lower the room air temperature. The system was able to cool down the rooms into the thermal comfort range for PB model, but the low air temperature in the OB model still not able to help to reduce the internal relative humidity. The energy consumption with the selected HVAC system in the building model will be discussed in the next section (Section 7.4.3).

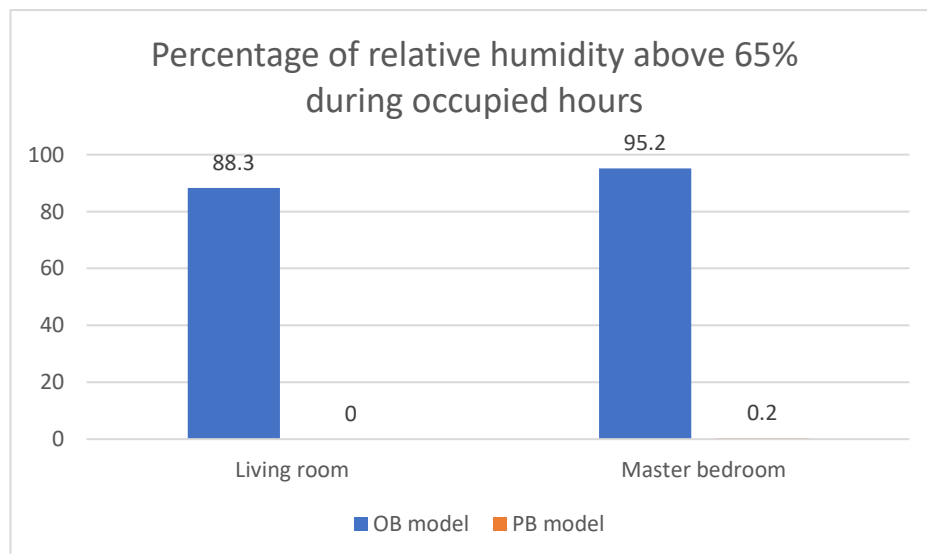


Figure 7-33 Percentage of relative humidity above 65% during occupied hours.

7.4.2 Using air conditioned (AC) and dehumidifier

The first analysis indicated that for OB model, the relative humidity in the living room and master bedroom cannot be lowered if the building model built was only using AC as a HVAC system. In this section, the experiment was to apply a dehumidifier to support the air conditioning in lowering room relative humidity into the comfort level. The same building model that was using AC was reused in this subchapter, and a dehumidifier was added into the HVAC system in the OB model and PB model to study the impact of the dehumidifier in the built Passivhaus building model in IES VE software. The HVAC template used in this simulation was modified type 07c template: Multizone Variable Air Volume Reheat System, that was added with additional desiccant dehumidifier (Figure 7-34). The HVAC system is using a chilled-water cooling coil in AHU, with added controls for mixed mode operation (natural and mechanical cooling/ventilation). Controls allow zone VAV flow if DBT or CO₂ levels get too high. Energy recovery heat exchanger for outdoor air pre-heat and pre-cool was to model the heat exchanger used in Passivhaus building.

By running the simulation in this HVAC template, the distribution of air temperature against relative humidity results is shown in Figure 7-35, indicating that the PB model was in the 23°C – 28°C air temperature range and 35% to 50% relative humidity range for the one-year period. But for PB model, the distribution of air temperature was around 20°C – 28°C and the relative humidity distribution was around 40% - 80%. Mostly, the air temperatures and relative humidities are in the highlighted area, with only some of PB model results outside the comfort range.

To study in more detail the building performance after the dehumidifier was added into the HVAC system, a yearly simulation result air temperature was made in Figure 7-36 and Figure 7-37. The building model graph indicated that the air temperatures in both areas for PB model, the master bedroom and living room area, were in the thermal comfort range for the whole time. The hourly air temperature indicates that the PB model can maintain the air temperature at around 24°C – 27°C. But the OB model was monitored mostly below thermal comfort range, with the air temperature range around 21°C - 25°C for the whole year.

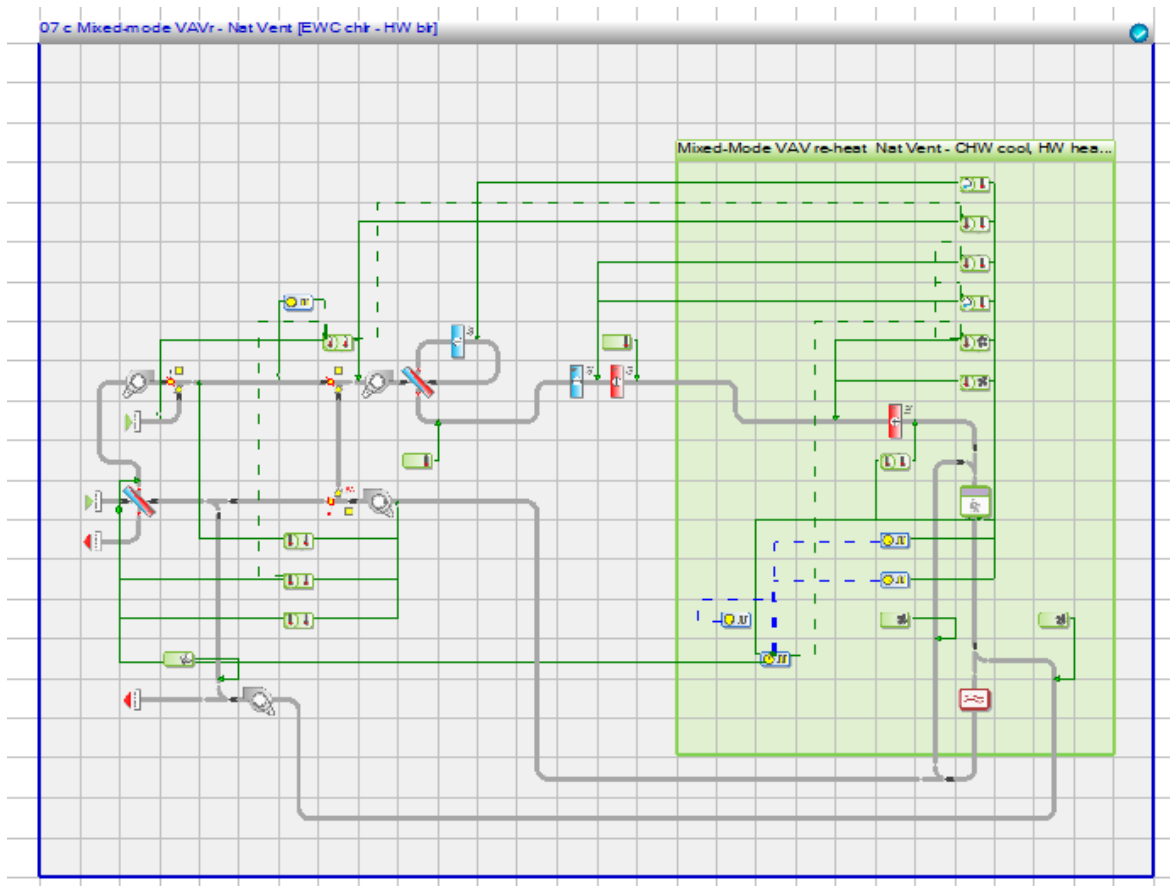


Figure 7-34 Modified HVAC template type 07c: Mixed-mode VAVr - Nat Vent, with additional desiccant dehumidifier.

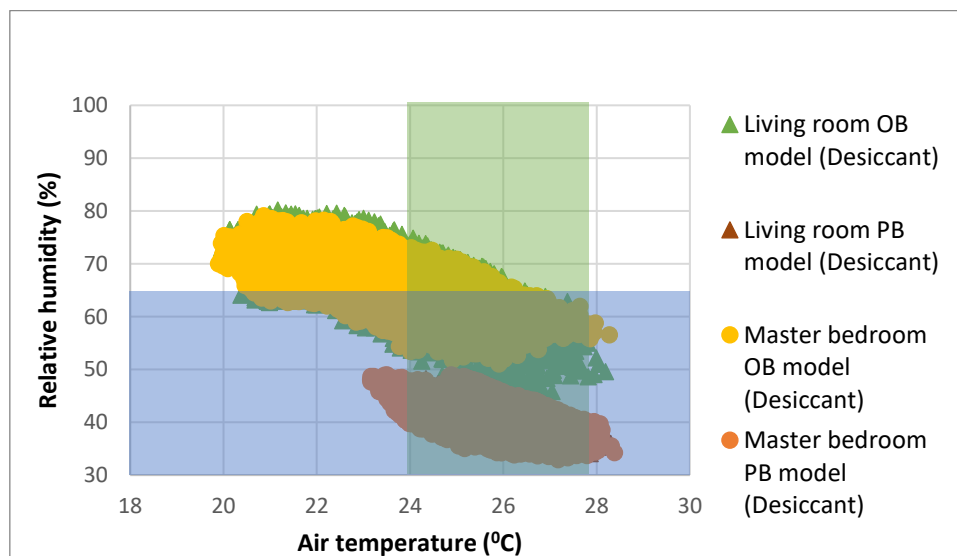


Figure 7-35 The relative humidity and air temperature distribution for one-year period in the building model with AC + dehumidifier.

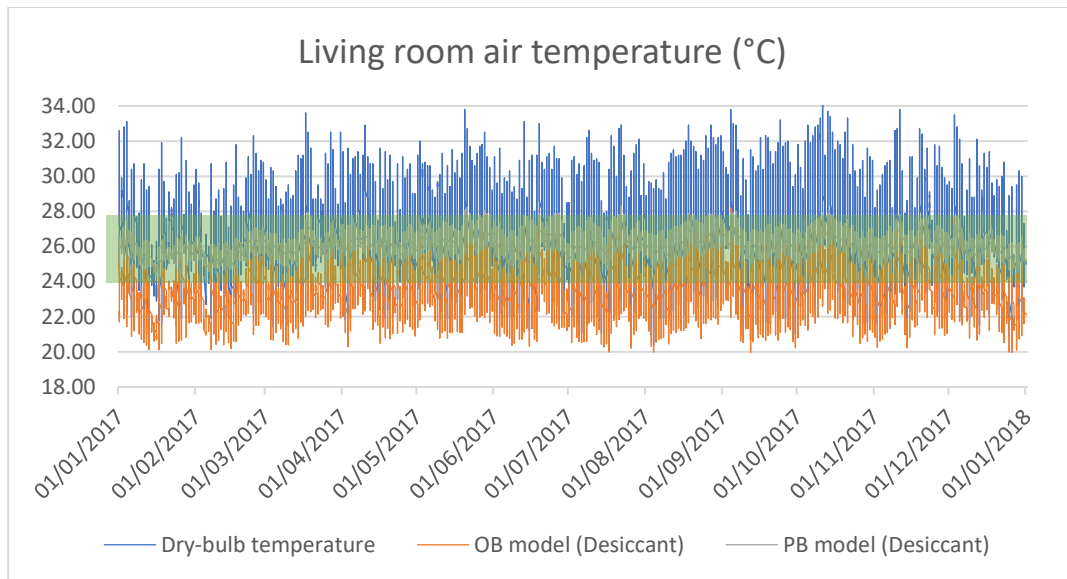


Figure 7-36 Living room air temperature comparison between OB model and PB model with AC + dehumidifier system.

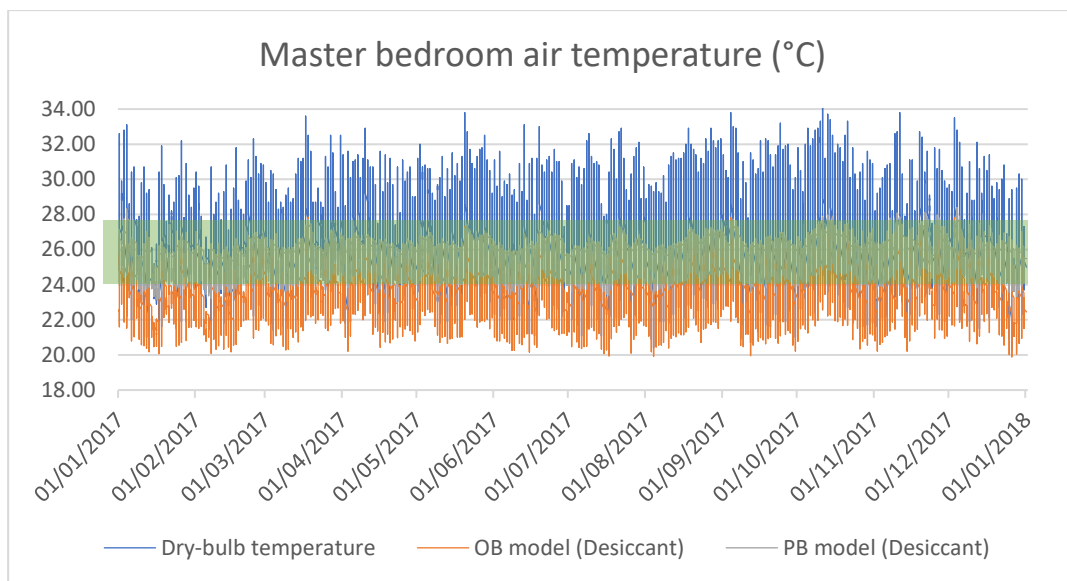


Figure 7-37 Master bedroom air temperature comparison between OB model and PB model with AC + dehumidifier system.

The one-week graph of air temperature comparison between OB model and PB model from 29 October until 6 November in Figure 7-38 and Figure 7-39 was made to look in more detail at the building relative humidity internally. The graph shows that PB model air temperatures in living room and master bedroom were stable even though the outdoor temperature was fluctuating. The OB model air temperatures in the living room and master bedroom were following the outdoor temperatures during the nighttime when the outdoor temperature was

dropping. But the maximum air temperature for the OB model was 26°C, which is still below the thermal comfort range for a hot and humid climate. The air temperatures for the PB model were more stable with the AC and dehumidifier system, with the air temperatures during the nighttime being warmer than external temperatures, but still in the thermal comfort range.

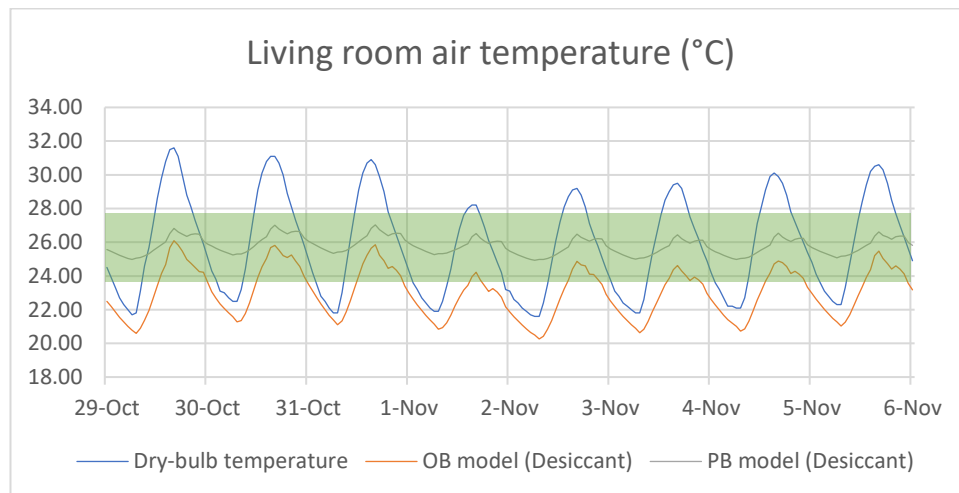


Figure 7-38 Living room air temperature comparison between OB model and PB model with AC + dehumidifier system from 29 October until 6 November.

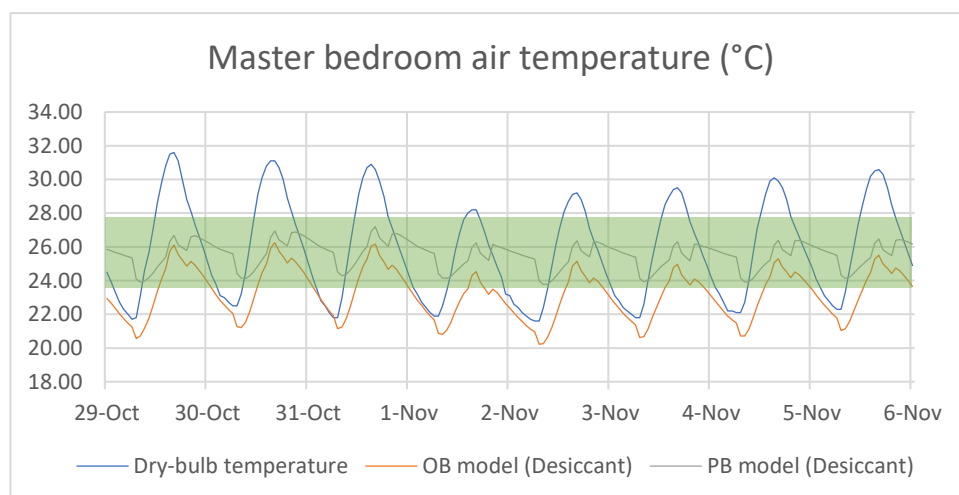


Figure 7-39 Master bedroom air temperature comparison between OB model and PB model with AC + dehumidifier system from 29 October until 6 November.

The relative humidity simulation results comparison in Figure 7-40 and Figure 7-41 indicate that with the AC and dehumidifier as the HVAC system, the PB model's relative humidities in

the living room and master bedroom were in the comfort range. The relative humidity for the PB model was maintained at around 40%. On other hand, the relative humidity results for the OB model was around 65%. For the OB model, there was around 50% of the occupied time above the comfort relative humidity (Figure 7-42). The dehumidifier was able to maintain the relative humidity in the comfort range for the PB model, but for the OB model the relative humidity was monitored sometimes to rise above 65%.

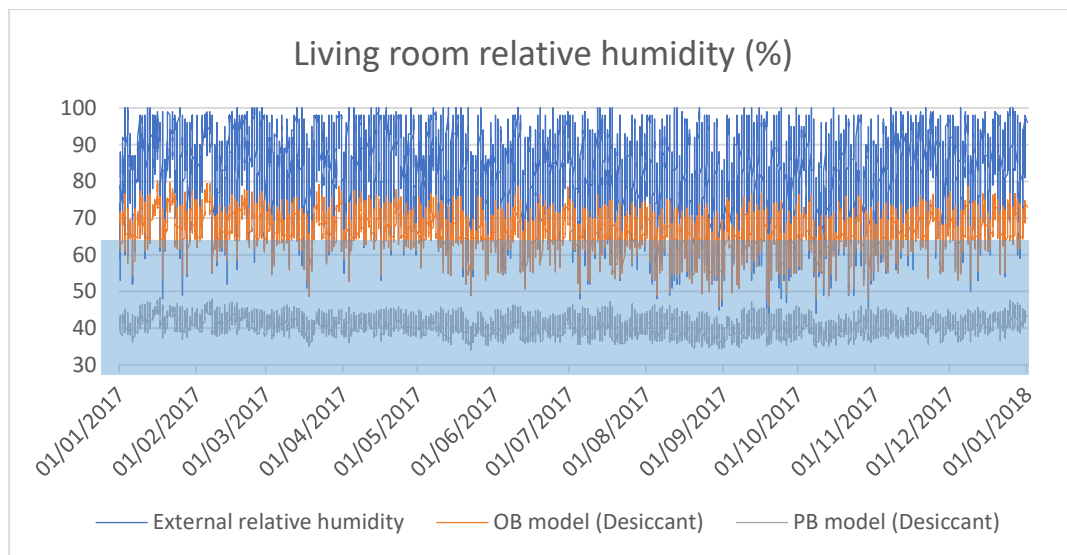


Figure 7-40 Living room relative humidity comparison between OB model and PB model with AC + dehumidifier system.

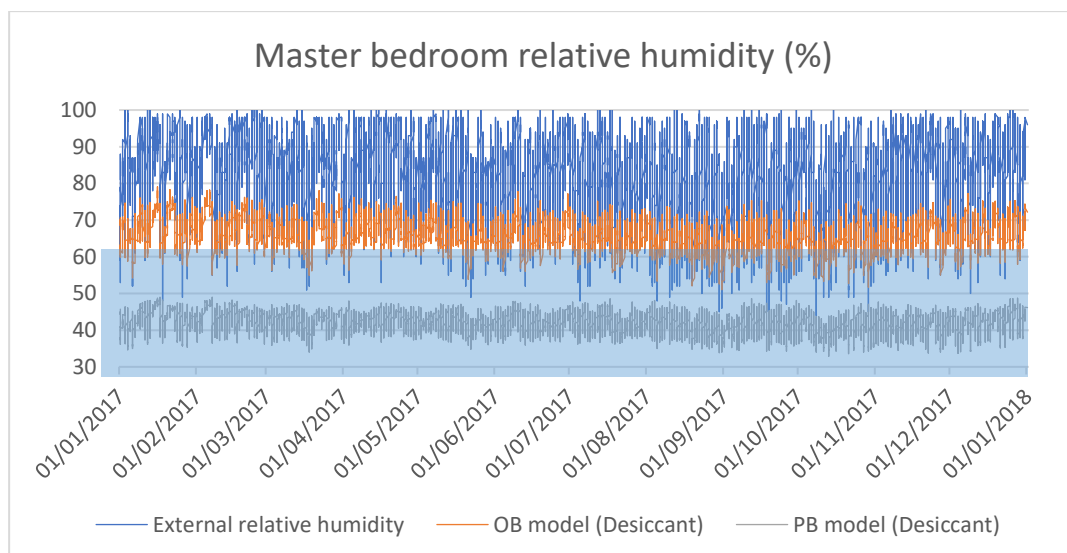


Figure 7-41 Master bedroom relative humidity comparison between OB model and PB model with AC + dehumidifier system.

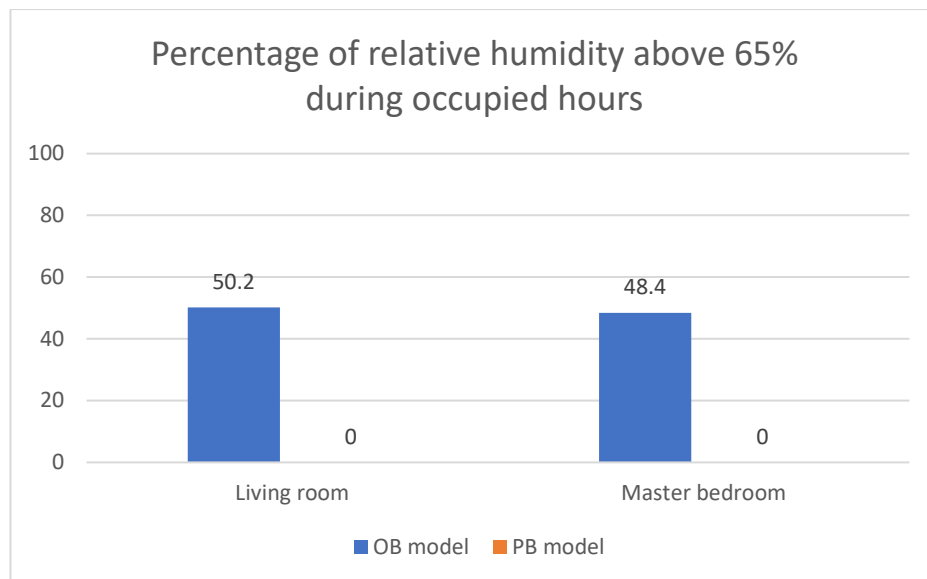


Figure 7-42 Percentage of relative humidity above 65% during occupied hours from OB model and PB model.

7.4.3 Energy demand comparison

Different HVAC systems were chosen to compare the ‘original building element model’ (OB model) and the applied Passivhaus building model (PB model) building performance with IES VE software. The performance of the building model was discussed in the previous chapter. There were two HVAC systems that were used in this comparison, the first using type 05d template that represent the air conditioning system, and the second was using the modified type 07c template that represented the dehumidifier and air conditioning system.

From the previous subchapter analysis, it is noticeable that by applying the HVAC system template in the building model it was possible to bring comfort to the PB model. But for the OB models there was still some periods that the building’s relative humidity inside the rooms were above comfort level. The analysis was also found that the additional dehumidification into the building HVAC system was able to improve the building air temperature and relative humidity compared with the building model that used AC only. The dehumidifier was also reducing the air temperature in this scenario to below the thermal comfort range, but this effort was able to reduce the internal relative humidity. To look at the effectiveness of this HVAC system and to look at the Passivhaus performance in the hot and humid climate, an energy comparison was made (Figure 7-43). The energy consumption of the OB model that used AC had the highest energy consumption compared to other building model scenario.

The OB model with AC used 46.5MWh of cooling energy annually, which was almost triple the cooling energy of the PB model using AC.

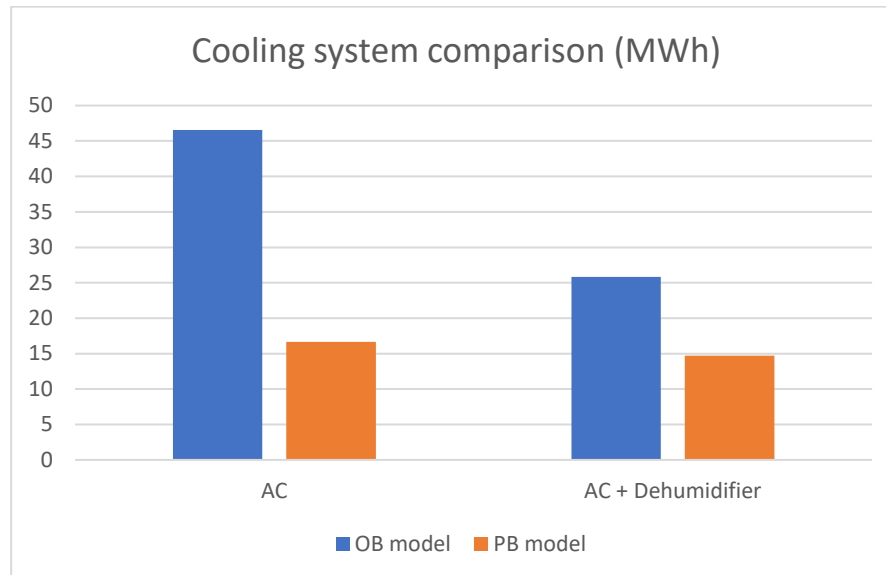


Figure 7-43 Yearly space cooling energy comparison between OB model and PB model.

The use of a dehumidifier in addition to the air conditioning in the house was able to lower the cooling energy in both the original building element and the Passivhaus model. The OB model had a significant cooling energy reduction by using the dehumidifier in addition to the AC. The cooling energy for the OB model that used AC + dehumidifier was 25.8MWh annually, which is almost half the OB model's cooling energy using AC only. The use of the dehumidifier was improving the building performance and at the same time reducing the energy.

For the PB model, even though the energy used was relatively the same for the PB model that used a dehumidifier + AC and AC only, based on the analysis in previous chapter the building performance of the PB model with additional dehumidifier was better. The energy comparison in Figure 7-43 is also indicated that the Passivhaus model had a significant cooling energy reduction compared to the original building element model. Based on the analysis, the Passivhaus model also had a stable room temperature and relative humidity for the whole year. The analysis indicated that the applied Passivhaus standard into building in tropical

climate was able to bring comfort to the house and at the same time was able to reduce the cooling energy that used by original building element.

7.5 Summary

This thesis explored the Passivhaus approach in a tropical climate building. PHPP, DesignBuilder and IES VE 2018 software were used to study the output from the application of the Passivhaus standard on the validated building model house. The analysis in PHPP software had indicated that wall insulation was important in the tropical climate, but additional insulation thickness in the wall did not improve the building performance. The same situation was happening with glazing type, where double and triple glazing were indicating relatively the same performance. But the analysis indicated that it is important to have roof insulation in the Passivhaus building in a tropical climate to reduce the cooling energy significantly. However, housing built in a hot and humid climate might not require any floor insulation. Introducing floor insulation in the Passivhaus building model suggested a higher cooling energy demand. This finding in PHPP was emphasized by the IES VE analysis, where removing the floor insulation from the Passivhaus building model reduced the cooling energy. The analysis on the effectiveness of floor insulation in the Passivhaus building is discussed in the Chapter 8.

The analysis by DesignBuilder highlighted that the typical housing built in Jakarta Metropolitan Region will have high internal humidities that are mainly above the comfort level for most of the time. The use of AC only on the original building model and Passivhaus building model was not able to reduce the high relative humidities in the building, and a dehumidifier was needed to reduce the internal relative humidity. The analysis in DesignBuilder indicated that the system can reduce the internal relative humidity in the Passivhaus building model but the original building model was still facing high internal relative humidities even with the dehumidifier system.

The IES VE that was used to study the Passivhaus building model performance was able to model the AC with a dehumidifier system. The IES VE HVAC system can be adjusted to push the room air temperatures and relative humidities into the comfort range. The analysis made in IES VE was able to reduce cooling energy compare to the original building layout. The validation results showed that the building model in IES VE software for a hot and humid

climate was and could be used for further analysis of Passivhaus approaches. With the application of the Passivhaus standard to the building model, the additional wall and roof insulation, introduction of double-glazed windows and the use of AC or AC + dehumidifier, the IES VE 2018 simulation results showed that the Passivhaus building model had stable air temperatures and relative humidities for the whole year. The finding has also suggested that the Passivhaus application had significantly reduced the cooling energy. By applying the Passivhaus standard, the cooling energy yearly can be reduced by half compared to the original building element and at the same time bring comfort to the occupants.

In conclusion, it is noticeable that the high relative humidity is the big problem for tropical buildings. Air-conditioning can act as a dehumidifier by lowering indoor air temperature to reduce the moisture capacity of the indoor air and decrease relative humidity. However, as expected, lowering the cooling set point increased energy use. Using a dehumidifier enabled the maintenance of a stable relative humidity while reducing the cooling energy. The modeled house needed a means of active dehumidification to achieve optimal control over the comfort zone. Cooling with dehumidification was the key strategy in reducing relative humidity in the modeled house. The outdoor air should be cooled and dehumidified before it is circulated in the rooms. From the analysis, applying Passivhaus into the building indicated that this scenario had lowered energy usage compared to the original building element.

Chapter Eight

8 GROUND TEMPERATURE AND FLOOR INSULATION IN APPLIED PASSIVHAUS DWELLING IN JAKARTA

8.1 Overview

Radiant cooling is one strategy to cool buildings and Concrete Core Temperature Control (CCTC) is a floor cooling strategy (Austrian Embassy Jakarta, 2019). A chiller pumps cool water around pipes that are cast inside the floor to cool the slab and later cool the room temperature (Oettl, 2014). In tropical climates, ground soil temperatures range from around 15°C to 25°C, and so can be much cooler than the ambient air temperature (Alam et al., 2015). Floor slabs in contact with the ground can, therefore, be effective in cooling a building. The use of ventilation to try and cool buildings can transfer high amounts of moisture in to rooms, resulting in poor internal thermal and health conditions in which the optimum humidity levels of 40% to 60% (Katili et al., 2015) are exceeded. It is, therefore, necessary to create design approaches to building design that can keep indoor air humidity low while still reducing cooling energy consumption. This chapter presents the testing of a house model developed using the commercial dynamic thermal simulation software IES VE. This chapter is describing the development of a Passivhaus standard for housing built in Indonesia that works for both thermal comfort and energy efficiency. The energy advantages from cool ground temperatures with no floor insulation were observed in the development of the house model.

8.2 The ground temperature model used in the simulation

Soil properties are difficult to generalize because of local heterogeneity and the lack of broad based data; also, soil condition is not a standard variable collected at most weather stations (Waring and Running, 2008). Available literature indicates that underground soil temperatures can vary from 8°C to 27°C in some parts of the world, especially in cold-dominated areas (North America), and between 15°C and 25°C in tropical climates (Alam et al., 2015). The average monthly ground temperature in Jakarta, based on the weather analysis software Climate Consultant, is 26°C (Milne, 2019). Because soil temperature responds to the net effect of the daily surface energy balance, it can be estimated by computing a running average of air temperature, with progressively longer integration times as soil depth increases (Hu and Feng, 2003). The analysis method for ground construction setting in IES VE software is based on EN-ISO 13370 (IES-VE, 2019).

Utilizing the literature information about ground temperature above, the setting on the IES VE simulation was set. The ground temperature in the IES VE software was made using outside air temperature with an offset temperature profile. With the parametric study on the simulation result from the IES VE software, it was indicated that an offset temperature profile at - 5°C from the external temperature was appropriate for this simulation. With the ground floor adjustment made and together with other adjustment made on the IES VE setting, the simulation result was satisfactory (see section 6.3.3).

The ground temperature that was made by offsetting external air temperature by -5°C was analysed further. The predicted ground temperature based on this analysis is displayed in Figure 8-1. The graph indicated that there was more than 75% of the time when the ground temperatures were below the thermal comfort range (24°C - 27.8°C). This finding suggests that it might be possible for the ground to act as heat sink. Through overcooling season for several months, there will be a net benefit from the slab that was cooled by the ground.

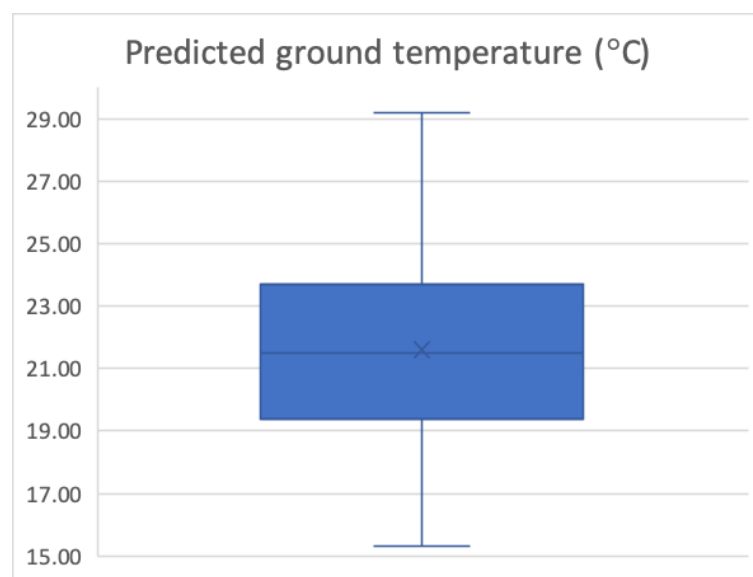


Figure 8-1 Box plot of predicted ground temperatures for one-year period.

8.3 Jakarta Passivhaus performance without floor insulation

The analysis in section 7.2 about PHPP indicates also that removing the floor insulation had a significant effect on lowering the building temperature and potentially reducing the building energy demand. To further analyze the impact of floor insulation in the Passivhaus building model, a study in IES VE software was made. The comparison of the Passivhaus building model (PB model) with a Passivhaus without floor insulation building model (PB model without floor

insulation) was made to look at the impact on the thermal comfort range and building energy when the floor insulation was removed from Passivhaus building. The performance of these two scenarios will be made to explore the potential of the ground floor act as a thermal sink and provide radiant cooling of rooms. The analysis method for ground construction setting in IES VE are based on EN-ISO 13370 (IES-VE, 2019). This method takes as inputs ground conductivity, floor plan characteristic dimension, wall thickness, insulation details and depth below ground level.

The PB model without floor insulation in IES VE was made by removing the floor insulation from the PB model created in IES VE software. The settings used in the model are listed in Appendix N and Appendix O. To compare the floor insulation impact on the Passivhaus building built in a hot and humid climate, the same HVAC setting on the IES VE software was applied in these two scenarios. Since the study on the Passivhaus in section 7.4.1 indicated the importance of a dehumidifier on reducing the cooling energy, in this study the HVAC system that was applied to the two building models was an AC and desiccant dehumidifier template. The AC and dehumidifier template used was the system described in section 7.4.2. In the previous chapter it was also highlighted that the use of a dehumidifier was able to reduce the cooling energy and at the same time create more stable room air temperatures and relative humidities.

The simulation results with the setting described above are presented through graphs shown on the next page. The relationship between air temperature and relative humidity in both models was made to see the distribution of room temperature and relative humidity. Figure 8-2 indicates that both PB model and PB model without floor insulation can perform well with the applied setting. The air temperature and relative humidity was mostly in the comfort range, with air temperature monitored a few times below or above the thermal comfort range. The setting of AC and dehumidifier was to be turned on when the rooms were occupied, so the temperatures above thermal comfort level were happening when the building was not occupied. But with the applied system, the relative humidity for both scenarios were monitored to be always below 65% annually.

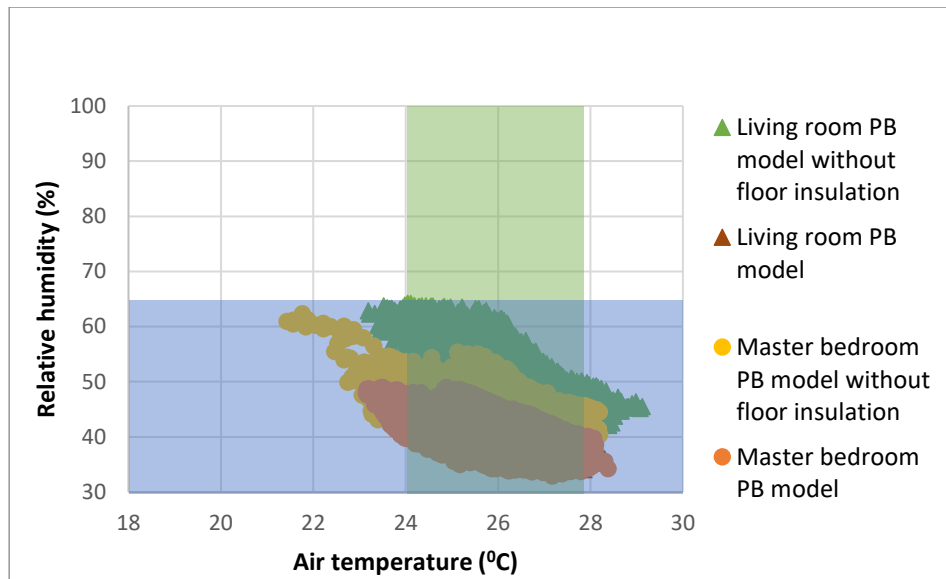


Figure 8-2 The relative humidity and air temperature distribution for one-year period in the building model with AC and dehumidifier.

For the living room area, Figure 8-3 indicated that with the HVAC system the room air temperature can be maintained in the thermal comfort range for the whole year. The same situation was taking place in master bedroom (Figure 8-4), where the graph clearly indicated that the air temperatures of PB model and PB model without floor insulation were both in the thermal comfort range. However, the air temperature for the PB model seems sometimes to be below the thermal comfort range.

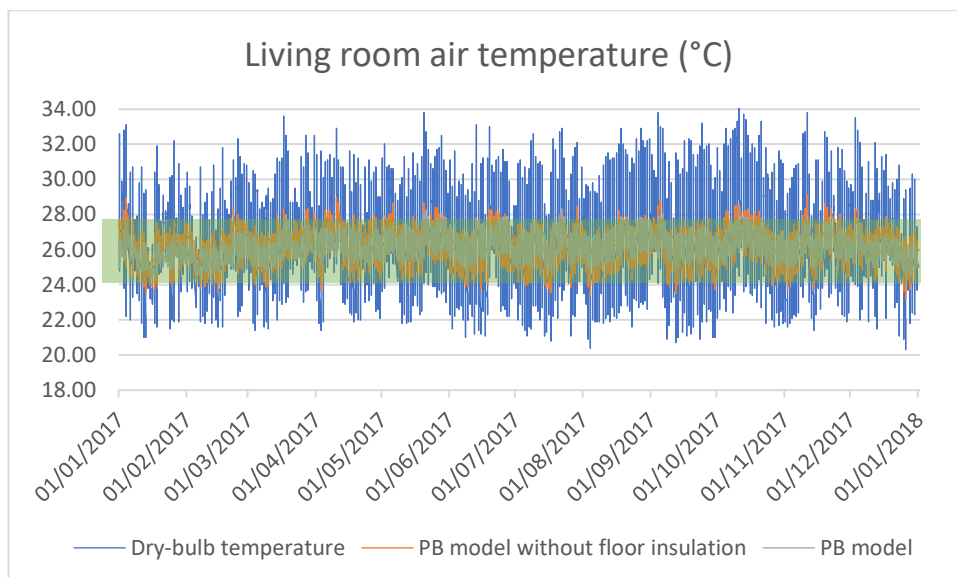


Figure 8-3 Living room air temperature comparison between PB model with PB model without floor insulation.

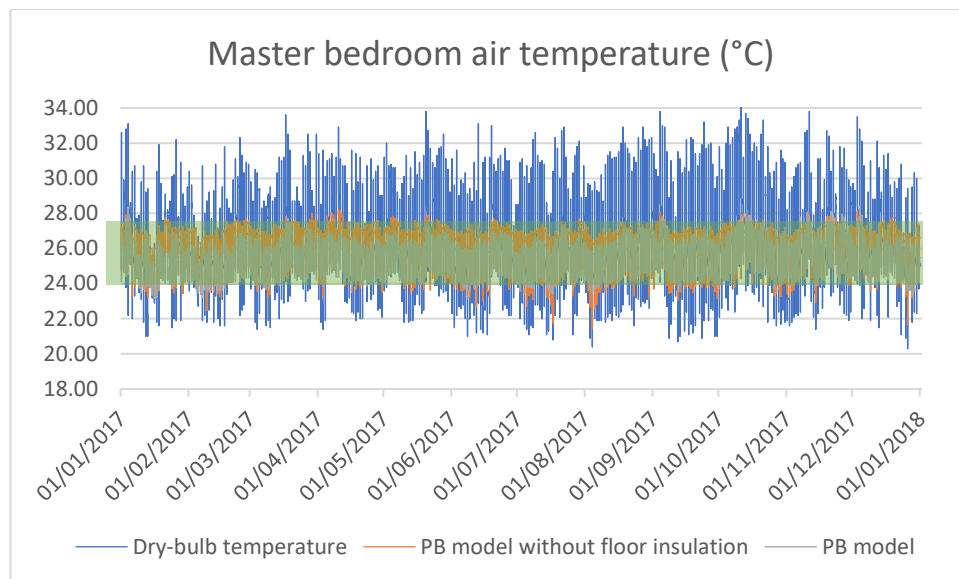


Figure 8-4 Master bedroom air temperature comparison between PB model with PB model without floor insulation.

The simulation relative humidity results that are shown in Figure 8-5 and Figure 8-6 indicate that the selected HVAC system with AC and dehumidifier in both scenarios was able to maintain the room relative humidity in the comfort level for the whole year, even though the relative humidity in the PB model without floor insulation was higher than for the PB model. The PB model's relative humidity was lower than the PB model without floor insulation for both rooms' analyses. The PB model's relative humidity was more stable (40% to 50% humidity), whereas the PB model without floor insulation was seen ranged from 50% to 60% humidity.

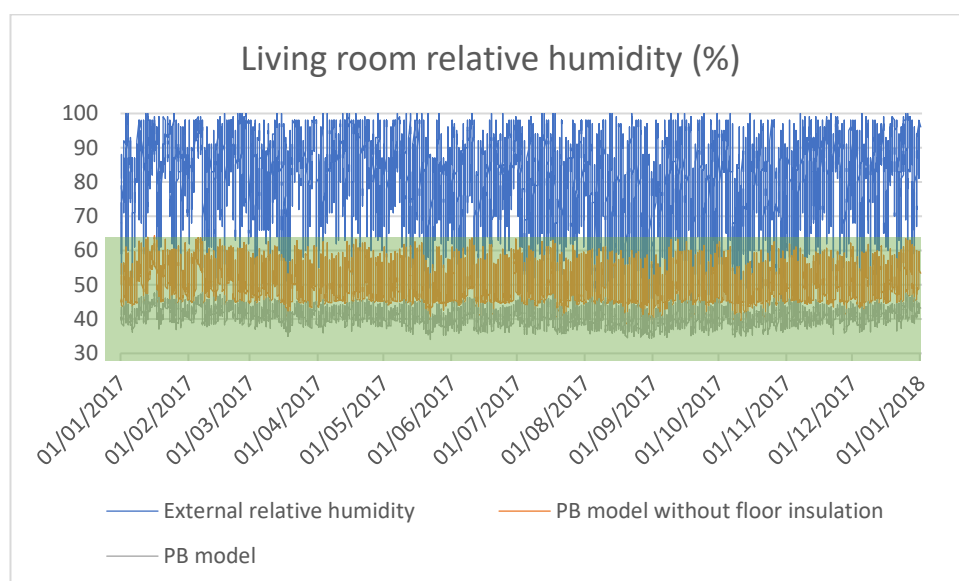


Figure 8-5 Living room relative humidity comparison between PB model with PB model without floor insulation.

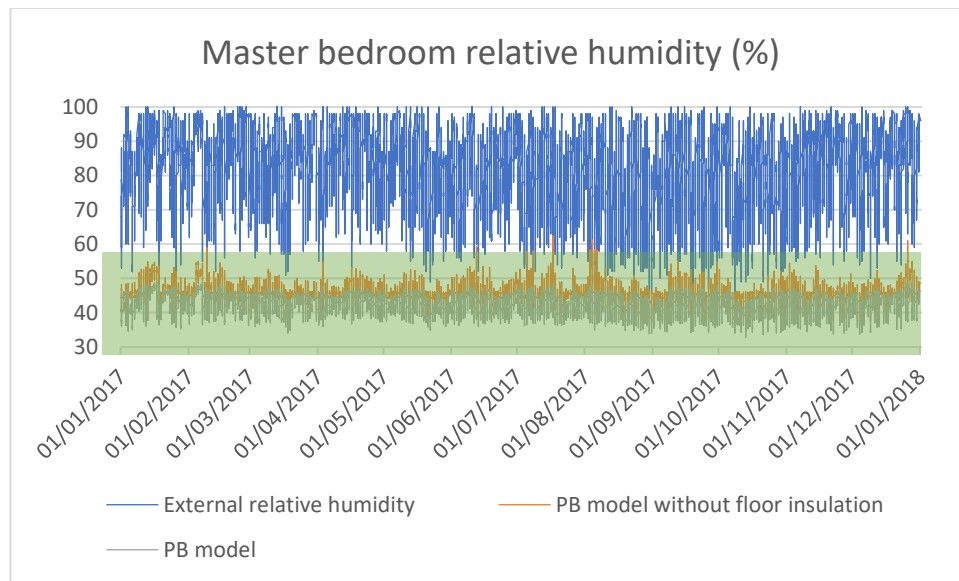


Figure 8-6 Master bedroom relative humidity comparison between PB model with PB model without floor insulation.

The performance of PB model and PB model without floor insulation was in the comfort level for all the time with the selected HVAC system. The effectiveness of removing floor insulation can be seen from the cooling energy consumption. Figure 8-7 suggests that the cooling energy from the PB model without floor insulation was lower than the PB model, where there was about 35% energy drop just from removing the floor insulation from the Passivhaus building.

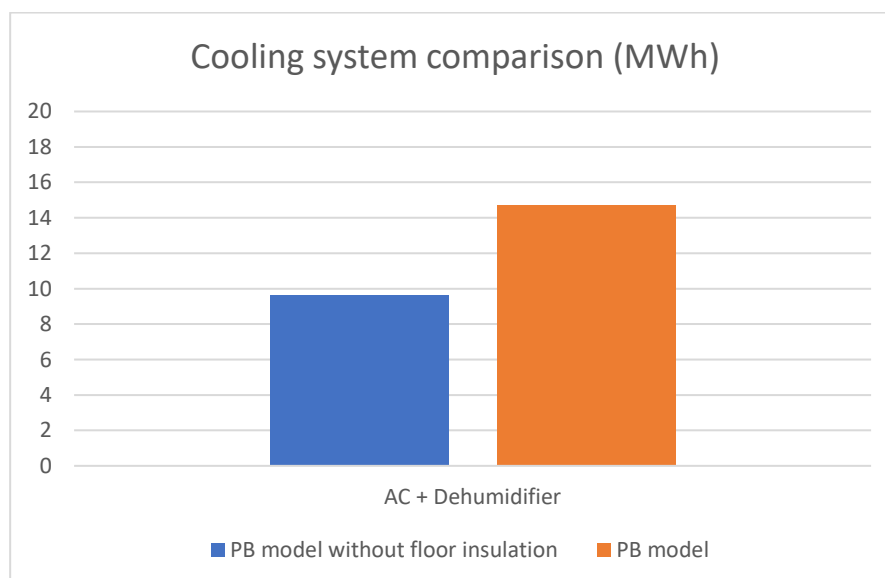


Figure 8-7 Yearly space cooling energy use for the PB model with PB model without floor insulation.

8.4 The Passivhaus without floor insulation building model performance in the future climate scenario

The future climate scenarios were investigated, considering a medium to high climate impact on the Passivhaus project in Jakarta - Indonesia. Timeline series for current weather, 2050 and 2080 were chosen using morphed (EPW) weather files generated through statistical generation weather tools in Meteonorm to represent the current and future climates. Two Special Report on Emissions Scenarios (SRES) were chosen for the selected future climate timeline series:

- the A1B, which assumes rapid economic growth and a mixed energy supply; and
- the B1, which assumes rapid economic growth but with a cleaner, more ecological energy supply.

The analysis was made through IES VE software by using the building model built in this research. The building model used for future climate analysis was based on the Passivhaus without floor insulation building model, since this model had the best performance compared with the others building model scenario in this research. All the building components and construction materials were assumed to be identical for the two timeline scenarios, and the current systems and construction materials were assumed identical. The building model was using the same AC and dehumidifier system as the HVAC system, and used to cool and dehumidified the building into the thermal comfort range. The selected weather data were implemented into the IES VE building model to look at the impact of future whether into the built model.

The simulation run in the IES VE with all the building model scenario indicated that the air temperature and relative humidity were able to be maintained in the comfort range. The air temperatures during the occupied hours in the master bedroom and living room were able to be maintained in the thermal comfort range with the applied HVAC system, and the relative humidity could be maintained to be below 60% for the whole year. With this performance, the cooling energy was then compared to look at the effectiveness of the Passivhaus building without floor insulation in the future climate scenario. The comparison of building cooling energy shown in Figure 8-8 was between the Passivhaus building model without floor

insulation in the current weather, 2050 A1B and B1 weather scenario, and 2080 A1B and B1 weather scenario.

From Figure 8-8 can be seen that in the future climate scenario, the building models had higher energy consumptions compared to current climate. For A1B scenario in the 2050s there are around 60% increase compared to the current scenario. For B1 in 2050s has a slightly lower increase in energy consumption compare to A1B 2050s scenario, that is around 37% raised compared to the present use. The A1B and B1 scenario in 2080s has relatively the same cooling energy with A1B scenario in 2050s. But compared to the Passivhaus building model and 'original building element building model', the future climate of Passivhaus without floor insulation are still having a lower cooling energy demand.

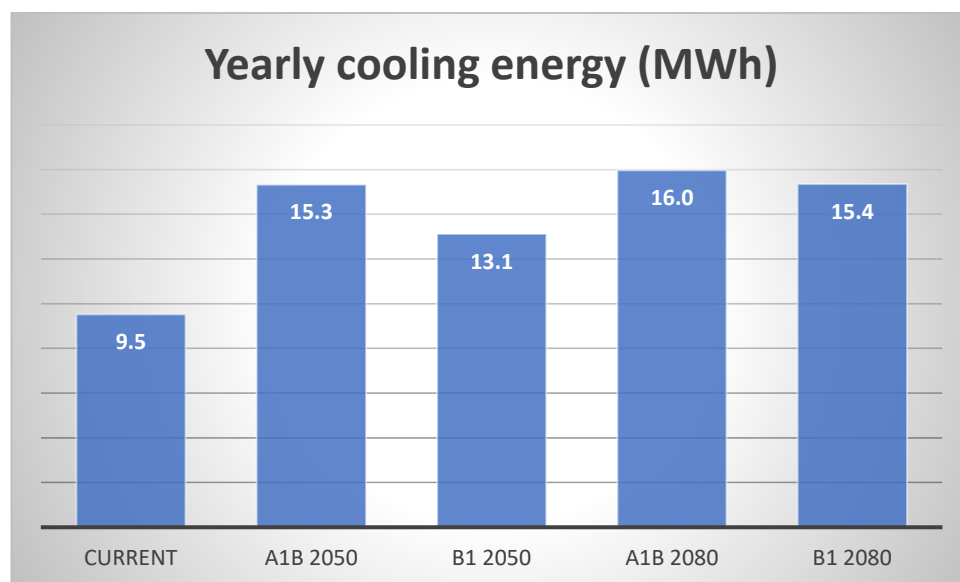


Figure 8-8 Yearly cooling and dehumidifier energy comparison from different climate data scenario.

8.5 Summary

This chapter was explored the effect of ground temperature and ground insulation on the performance of a Passivhaus-enhanced dwelling in a tropical climate. The original dwelling was monitored to gain air temperature, relative humidity and activity schedule data that were used to create a validated IES building model. The validation process identified ground temperature as an important variable in the model. The impact of coupling the building to the ground without using insulation was also examined and found to reduce cooling energy demand whilst maintaining good comfort levels.

The Passivhaus building model that was built in IES VE 2018 software was then used to study the output from the application of the Passivhaus standard without floor insulation. Cooling and dehumidification were key strategies in reducing relative humidity in the modeled house. With IES VE simulation, dehumidification by using a desiccant dehumidifier can be simulated. With the application of the Passivhaus standard and the Passivhaus without floor insulation, the IES VE 2018 simulation results showed that both building models had stable air temperature for the whole year with AC + desiccant dehumidifier system. Based on the current analysis, after the Passivhaus application into the modeled house and by using AC and desiccant, the air temperature and relative humidity could be kept in the thermal comfort range. Modelling the Passivhaus without floor insulation and using AC + desiccant dehumidifier, indicated that the building was all the time in the thermal comfort range for the whole year. But by removing the floor insulation from the Passivhaus building model, the energy used can be cut around 35%. The analysis on the building model in the future climate scenario also indicated a lower energy consumption with Passivhaus without floor insulation building model, when comparing the model with the Passivhaus and the original building.

The predicted values from IES indicated that comfort levels were achieved when floor insulation was removed from the Passivhaus building model. Modelling heat flows through floors is complicated because there are many hard-to-quantify physical variables (such as soil conductivity) and there can be a major impact from time delays, thermal storage and seasonal weather changes. While acknowledging these difficulties, this study took a snapshot of time for its modelling and used a very-well established software. The thermal simulation results did indicate that during the cooling season, there might be the potential for an uninsulated ground to act as heat sink in a tropical climate. Through overcooling season for several months, there may be a net benefit from not having a floor insulation. This scenario also had lower energy usage compared to Passivhaus with floor insulation and the original house layout. This finding highlighted the importance of using correct ground temperatures in dynamic thermal modelling. In some software the ground temperature is assumed to be at either air temperature or a fixed value below air temperature. For countries that experience very high level of solar gain on horizontal surfaces from a high sun, such as Indonesia, it would be useful to refine ground temperature assumptions.

Chapter Nine

9 CONCLUSION AND FINAL REMARKS

9.1 Overview

In this research, an effort was made to explore the likelihood of employing the energy-efficient building typology, “the Passivhaus standard”, in the context of residential buildings in Jakarta - Indonesia in particular and the hot and humid climate in general. This was accomplished through evaluating the performance of the Passivhaus building model in Jakarta. The assessment was completed by addressing the research objectives and the research questions stated in the introduction chapter, Sections 1.2 and 1.3. This chapter concludes the thesis and begins by presenting a summary of the research area, followed by the research main findings and limitations, and finally it ends by recommending further work built upon the findings of this study.

9.2 Summary

Global warming is a serious problem that the world faces today. As one of the top 20 countries that emitted the most carbon dioxide in 2015 (Union of Concerned Scientists, 2018), Indonesia has a significant role to overcome the issue since Indonesia's energy consumption has increased in recent years. However, in recent years the concern has grown beyond energy savings. A number of energy-efficient models have been built and tested in developed countries; moreover, some typologies are even included in future energy targets for a number of countries, such as low energy and zero energy buildings (Pittakaras, 2015). The energy-efficient models in the Indonesia is still in its infancy, with only a small number of models recognized and cited in the literature, one of which is the Austrian embassy that is described in this thesis.

The Passivhaus concept was introduced more than 25 years ago in Germany and has later spread widely in Europe. It is popular owing to its compact requirements and its significant energy savings and high levels of thermal comfort. However, in Indonesia, the concept of energy-efficient homes is relatively new. Compulsory thermal codes are not available in the area, resulting in end users being less interested in applying energy-efficient measures. Through this research, the performance of the Passivhaus project in Jakarta was investigated and its outcomes discussed. The assessment process was carried out by validating the building model, conducting a comparative analysis between the performance of the original building

element (OB model) and applied Passivhaus standard building (PB model). The OB model was built following the typical building built in Jakarta, and a PB model was built using applied Passivhaus criteria in a Jakarta typical building.

9.3 Research Main Findings

This section refers back to the questions listed in Chapter One, Sections 1.3. It summarizes the research questions and highlights the findings related to each by referring to the chapters that discussed the specific topic.

1. What is the importance of introducing the Passivhaus standard as an energy-efficient model for Jakarta?

The importance of introducing energy-efficient measures to buildings is not only a current concern but is also considered a future requirement for buildings. With the current concern of the effect of climate change, energy saving is one of the main aims of realising low energy models that become one solution for preventing climate change. The Passivhaus approach is considered to be one of the fastest growing energy-efficient standards; its basics are originating from a thorough understanding of how buildings operate and how energy within buildings could be minimised while delivering high levels of thermal comfort. Passivhaus buildings have been mentioned as one of the routes towards achieving zero energy buildings, which are seen as the future of the housing stock in developed countries. The lack of such typologies in Jakarta - Indonesia has initiated this research, and the Passivhaus approach was chosen as a result of its carefully constructed criteria and its famous high-performance levels.

2. How well does the Passivhaus building model perform in comparison to the standard building model with tropical climate?

A full assessment of a standard building and a Passivhaus building model was demonstrated in Chapter 7. The building model built in DesignBuilder and IES VE software have suggested that there is an improvement in applying the Passivhaus concept into the typical dwelling in a hot and humid climate. The building model built in IES VE had indicated that the Passivhaus building had stable air temperatures and relative humidities compared to a standard building model. By using the same air-conditioned and dehumidifier system in the building model, the Passivhaus building model was able to reduce by half the cooling energy compared to the standard building.

3. What key features of the Passivhaus building can be applied to local buildings to improve their performance and sustainability?

From the validation process and building analysis process can be seen that dehumidifier was the key for a building built in a hot and humid climate. The Passivhaus standard application was able to make stable air temperatures and relative humidities internally, and with the help of air-conditioning and dehumidifier, the thermal comfort range could be achieved with less energy compared to the standard building built in the region. The different scenario of wall insulation thickness described in section 7.2 indicated a slightly different building performances between one another. It could be understood that wall insulation was important in reducing cooling energy but increasing the wall insulation beyond a certain thickness does not give a better performance to the building. Conversely, having floor insulation was adding more energy demand to the building model, while removing the floor insulation can reduce further the lower energy demand of Passivhaus.

4. If the Passivhaus building was expected to perform better than the standard building at the present time, how well is it expected to perform under the impact of climate change?

On the analysis, the performance of the Passivhaus building model was validated and predicted for the present-day scenario, and the model were replicated throughout the future scenarios. The findings were described in section 8.4 of the 'Ground temperature and floor insulation in applied Passivhaus dwelling in Jakarta' chapter. The Passivhaus building model without floor insulation (the model with lowest energy used) was likely to continue consuming less energy than the original building layout. The cooling demands of the Passivhaus without floor insulation in the future climate scenario were still lower than the current energy used by typical building in Jakarta.

5. Is it possible to create comfort on the Passivhaus building without an air-conditioning system?

The thermal comfort range was explained in section 5.5 and was used in this research to specify the comfort level for the Jakarta area. The analysis in the DesignBuilder software that was described in Chapter 7 indicated that the Passivhaus building model was able to be maintained in the comfort level with the additional dehumidifier. The analysis indicated that AC only was not able to reduce the internal relative humidity. Analysis with IES VE software

indicated that adding a dehumidifier in the Passivhaus building HVAC system was able to reduce by 10% cooling energy demand compared to the AC system only and maintained the rooms in the comfort range.

6. What are the barriers that may be associated with the implementation of the Passivhaus concept in Jakarta?

Through the literature review and the previous experiences of Passivhaus buildings, several implications could be predicted for the case of Passivhaus standard application in Jakarta with its hot and humid climate. Possible implications have been discussed within Part Two of this research. The original Passivhaus study pointed out that there were financial burdens associated with building to the Passivhaus standard. The analysis indicated the buildings were more successful in adopting Passivhaus concepts in Germany and Austria as a result of mutual architecture, technology and first adoption of the standard. For the Passivhaus in Jakarta, it is suspected that similar issues would arise.

Passivhaus requires airtightness in the built building, and special skills are needed to overcome several issues related to construction detailing that may cause infiltration problems. Airtightness detailing has not been a common skill within the construction community in the area and may pose a challenge towards achieving Passivhaus criteria. There is also a lack of ventilation systems availability in the local market and the knowledge to make an informed choice on the most effective system. Since insulation is not a common material in building construction in Indonesia, the added costs of constructing according to the Passivhaus standard will increase the dwelling construction costs. Finally, the investment costs associated with the adoption of the Passivhaus standard may not be justified given the highly subsidised energy tariffs. A life cycle cost analysis is needed to study the effectiveness of Passivhaus application into the typical house in Indonesia, and enforcement laws that impose energy efficiency within the residential sector are also needed to push the industry to move towards low energy building.

In conclusion, and by referring to the thesis hypothesis; in theory, the Passivhaus standard could be applicable as a low energy standard in Jakarta - Indonesia. Through the assessment carried out in this research, evidence has shown that close to Passivhaus standards were achievable. But life cycle cost analysis is required to study the effectiveness and potential

saving from Passivhaus standard application, and the enforcement law is needed to support the building industry move toward energy saving products.

9.4 Research Uncertainty and Limitations

This research attempted to explore the energy performance and thermal comfort of a virtual Passivhaus building built in Jakarta – Indonesia with its hot and humid climate. The scope of this research was limited to the validating building model in the building energy software and assessment of a single house to be built with Passivhaus standard in the context of Jakarta – Indonesia with hot and humid climate. Assessment indicators were also limited to two aspects: thermal comfort and energy used (the comparison was based on the simulation results from energy building software only). The boundaries set by this research were undertaken partly due to available resources and the data that could be collected on-site. Assessing the performance of two building models built in building energy software, one representing a typical dwelling built in Jakarta and the other one a Passivhaus building model, allowed first-hand insight into how the Passivhaus building could perform in the hot and humid climate. The analysis was made on the individual building, and so the results cannot be generalized. However, an indication of the possible performance could be perceived.

The limitations on this research includes the nature of simulation outcomes, which are directed by a number of assumptions and inputs. Assumptions made in the simulation were including: the generated weather files, the thermal properties of the building materials used in the research, and assumptions related with the occupancy patterns and household appliances usage. The other limitation was also on deciding the HVAC template used in the simulation process that were able to represent the real HVAC system, because the air conditioning and dehumidifier used was a domestic scale, but the software HVAC system are mainly concentrated on big scale projects.

Finally, inconsistencies were found when comparing the results obtained from DesignBuilder and IES-VE in term of the cooling loads. The discrepancies that resulted were due to two main reasons: (1) the nature of calculations embedded in each tool, and (2) the different HVAC system's assumptions made in each tool. There is a big difference between cooling energy in the simulation with DesignBuilder with the estimated energy use with IES-VE. There are also differences in the building performance when using this two different software, where in the

IES VE the HVAC system can be set to work to achieve comfort in the rooms but in DesignBuilder there were still high humidity values in the rooms.

9.5 Further Work and Final Remarks

The discussion of this research is mainly on the energy saving and the comfort level achieved in the building model. To be able to apply the Passivhaus standard into tropical climates, further discussion on the cost issue is required. The application of the Passivhaus concepts in tropical climates still needs further analysis because the use of insulation, double glazing, and applying air-tight building is not a common practice in Indonesia. Besides the additional construction cost for the building, the quality of construction workers needs to be improved, especially for residential construction workers. Capital and life cycle costs needs to be quantified to judge the economic and technical feasibility of applying Passivhaus standard to tropical buildings.

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Appendix

APPENDIX A

Construction data input in DesignBuilder: Johor Bahru building model for validation.

Table A-1 External wall's fabric data

External wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table A-2 Internal wall's fabric data

Internal wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table A-3 External party wall's fabric data

External party wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table A-4 Calculated glazing data

Calculated glazing data _ 6mm single clear glass	
Total solar transmission (SHGC)	0.819
Direct solar transmission	0.775
Light transmission	0.881
U-value (ISO 10292/EN 673) (W/m ² -K)	5.718
U-value (W/m ² -K)	5.778

Table A-5 Ground floor's fabric data

Ground floor's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Floors (ground)	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.750	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Concrete slab	287
Layer 2	Cement screed	22
Innermost layer (Layer 3)	Ceramic tile	8

* Refer to DesignBuilder user manual (2019)

Table A-6 First floor's fabric data

First floor's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Floors (ground)	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.810	
		Thickness (mm)
Number of layers	4	
Outermost layer (Layer 1)	Cement plaster	20
Layer 2	Concrete slab	50
Layer 3	Cement screed	15
Innermost layer (Layer 4)	Ceramic tile	5

* Refer to DesignBuilder user manual (2019)

Table A-7 Internal ceiling's fabric data

Internal ceiling's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Ceilings	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.125	
		Thickness (mm)
Number of layers	1	
Single layer	Ceiling board (6mm)	6

* Refer to DesignBuilder user manual (2019)

Table A-8 Pitched roof fabric data

Pitched roof fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Roofs	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.662	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Clay roof tile	25
Layer 2	Standard insulation	5.4
Innermost layer (Layer 3)	Aluminium foil	5

* Refer to DesignBuilder user manual (2019)

APPENDIX B

Schedule data input in DesignBuilder: Johor Bahru building model for validation.

1. Occupancy schedule

Schedule:Compact,
Dwell_DomLounge_Occ,
Temperature,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 08:00, 0,
Until: 24:00, 0,
For: Weekends,
Until: 08:00, 0,
Until: 20:00, 1,
Until: 24:00, 0,
For: Holidays,
Until: 08:00, 1,
Until: 20:00, 0,
Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

2. HVAC schedule

Schedule:Compact,
Dwell_DomLounge_Occ,
Temperature,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 08:00, 0,
Until: 24:00, 0,
For: Weekends,
Until: 08:00, 0,
Until: 20:00, 1,
Until: 24:00, 0,
For: Holidays,
Until: 08:00, 1,
Until: 20:00, 0,

Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

APPENDIX C

Construction data input in DesignBuilder: Case study initial building model for validation.

Table C-1 External wall's fabric data

External wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table C-2 Internal wall's fabric data

Internal wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table C-3 External party wall's fabric data

External party wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.244	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	200
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table C-4 Calculated glazing data

Calculated glazing data _ 6mm single clear glass	
Total solar transmission (SHGC)	0.819
Direct solar transmission	0.775
Light transmission	0.881
U-value (ISO 10292/EN 673) (W/m ² -K)	5.718
U-value (W/m ² -K)	5.778

Table C-5 Ground floor's fabric data

Ground floor's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Floors (ground)	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.264	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Concrete slab	100
Layer 2	Cement screed	22
Innermost layer (Layer 3)	Ceramic tile	8

* Refer to DesignBuilder user manual (2019)

Table C-6 Internal ceiling's fabric data

Internal ceiling's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Ceilings	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.125	
		Thickness (mm)
Number of layers	1	
Single layer	Ceiling board (6mm)	6

* Refer to DesignBuilder user manual (2019)

Table C-7 Pitched roof fabric data

Pitched roof fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Roofs	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	6.061	
		Thickness (mm)
Number of layers	1	
Single layer	Clay roof tile	25

* Refer to DesignBuilder user manual (2019)

APPENDIX D

Schedule data input in DesignBuilder: Case study initial building model for validation.

1. Occupancy schedule

a. Master bedroom

Schedule:Compact,
Dwell_DomBed_Occ,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 06:00, 1,
Until: 13:30, 0.25,
Until: 15:00, 0.75,
Until: 18:30, 0.25,
Until: 24:00, 1,
For: Weekends,
Until: 06:00, 1,
Until: 13:30, 0.25,
Until: 15:00, 0.75,
Until: 18:30, 0.25,
Until: 24:00, 1,
For: Holidays,
Until: 06:00, 1,
Until: 13:30, 0.25,
Until: 15:00, 0.75,
Until: 18:30, 0.25,
Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

b. Living room

Schedule:Compact,
Dwell_DomLounge_Occ,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 07:00, 0,

Until: 10:00, 1,
 Until: 18:00, 0.5,
 Until: 22:00, 1,
 Until: 23:00, 0.66667,
 Until: 24:00, 0,
 For: Weekends,
 Until: 07:00, 0,
 Until: 10:00, 1,
 Until: 18:00, 0.5,
 Until: 22:00, 1,
 Until: 23:00, 0.66667,
 Until: 24:00, 0,
 For: Holidays,
 Until: 07:00, 0,
 Until: 10:00, 1,
 Until: 18:00, 0.5,
 Until: 22:00, 1,
 Until: 23:00, 0.66667,
 Until: 24:00, 0,
 For: WinterDesignDay AllOtherDays,
 Until: 24:00, 0;

2. HVAC schedule

a. Master bedroom (Natural ventilation)

Schedule:Compact,
 Dwell_DomBed_Occ,
 Fraction,
 Through: 31 Dec,
 For: Weekdays SummerDesignDay,
 Until: 06:00, 1,
 Until: 13:30, 0.25,
 Until: 15:00, 0.75,
 Until: 18:30, 0.25,
 Until: 24:00, 1,
 For: Weekends,
 Until: 06:00, 1,
 Until: 13:30, 0.25,

Until: 15:00, 0.75,
Until: 18:30, 0.25,
Until: 24:00, 1,
For: Holidays,
Until: 06:00, 1,
Until: 13:30, 0.25,
Until: 15:00, 0.75,
Until: 18:30, 0.25,
Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

b. Master bedroom (AC)

Schedule:Compact,
Dwell_DomBed_Cool Fifi,
Temperature,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 06:00, 1,
Until: 14:00, 0,
Until: 16:00, 0.5,
Until: 19:00, 0,
Until: 24:00, 1,
For: Weekends,
Until: 06:00, 1,
Until: 14:00, 0,
Until: 16:00, 0.5,
Until: 19:00, 0,
Until: 24:00, 1,
For: Holidays,
Until: 06:00, 1,
Until: 14:00, 0,
Until: 16:00, 0.5,
Until: 19:00, 0,
Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

c. Living room (Natural ventilation)

Schedule:Compact,

Dwell_DomLounge_Occ,

Fraction,

Through: 31 Dec,

For: Weekdays SummerDesignDay,

Until: 16:00, 0,

Until: 18:00, 0.5,

Until: 22:00, 1,

Until: 23:00, 0.66667,

Until: 24:00, 0,

For: Weekends,

Until: 16:00, 0,

Until: 18:00, 0.5,

Until: 22:00, 1,

Until: 23:00, 0.66667,

Until: 24:00, 0,

For: Holidays,

Until: 16:00, 0,

Until: 18:00, 0.5,

Until: 22:00, 1,

Until: 23:00, 0.66667,

Until: 24:00, 0,

For: WinterDesignDay AllOtherDays,

Until: 24:00, 0;

APPENDIX E

Schedule data input in DesignBuilder: validated case study building model.

1. Occupancy schedule

a. Master bedroom

Schedule:Compact,
Dwell_DomBed_Occ Fify,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 07:00, 1,
Until: 08:30, 0.25,
Until: 14:00, 0,
Until: 16:00, 0.25,
Until: 19:00, 0,
Until: 24:00, 1,
For: Weekends,
Until: 07:00, 1,
Until: 08:30, 0.25,
Until: 14:00, 0,
Until: 16:00, 0.25,
Until: 19:00, 0,
Until: 24:00, 1,
For: Holidays,
Until: 07:00, 1,
Until: 08:30, 0.25,
Until: 14:00, 0,
Until: 16:00, 0.25,
Until: 19:00, 0,
Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

b. Living room

Schedule:Compact,
Dwell_DomLounge_Occ Fify,
Fraction,

Through: 31 Dec,
 For: Weekdays SummerDesignDay,
 Until: 04:00, 0,
 Until: 07:00, 0.25,
 Until: 12:30, 0.2,
 Until: 18:00, 0.75,
 Until: 19:00, 1,
 Until: 24:00, 0.25,
 For: Weekends,
 Until: 04:00, 0,
 Until: 07:00, 0.25,
 Until: 12:30, 0.2,
 Until: 18:00, 0.75,
 Until: 19:00, 1,
 Until: 24:00, 0.25,
 For: Holidays,
 Until: 04:00, 0,
 Until: 07:00, 0.6,
 Until: 12:30, 1,
 Until: 15:00, 0.75,
 Until: 19:00, 0.25,
 Until: 20:00, 0.75,
 Until: 24:00, 0.25,
 For: WinterDesignDay AllOtherDays,
 Until: 24:00, 0;

2. HVAC schedule

a. Master bedroom (Natural ventilation)

Schedule:Compact,
 Dwell_Fify_Open window,
 Fraction,
 Through: 31 Dec,
 For: Weekdays SummerDesignDay,
 Until: 06:00, 0,
 Until: 14:00, 1,
 Until: 16:00, 0,
 Until: 19:00, 1,

Until: 24:00, 0,
For: Weekends,
Until: 06:00, 0,
Until: 14:00, 1,
Until: 16:00, 0,
Until: 19:00, 1,
Until: 24:00, 0,
For: Holidays,
Until: 06:00, 0,
Until: 14:00, 1,
Until: 16:00, 0,
Until: 19:00, 1,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

b. Master bedroom (AC)

Schedule:Compact,
Dwell_DomBed_Cool Fifi,
Temperature,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 06:00, 1,
Until: 14:00, 0,
Until: 16:00, 0.5,
Until: 19:00, 0,
Until: 24:00, 1,
For: Weekends,
Until: 06:00, 1,
Until: 14:00, 0,
Until: 16:00, 0.5,
Until: 19:00, 0,
Until: 24:00, 1,
For: Holidays,
Until: 06:00, 1,
Until: 14:00, 0,
Until: 16:00, 0.5,
Until: 19:00, 0,

Until: 24:00, 1,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

c. Living room (Natural ventilation)

Schedule:Compact,
Dwell_Fifty_Open window,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 06:00, 0,
Until: 14:00, 1,
Until: 16:00, 0,
Until: 19:00, 1,
Until: 24:00, 0,
For: Weekends,
Until: 06:00, 0,
Until: 14:00, 1,
Until: 16:00, 0,
Until: 19:00, 1,
Until: 24:00, 0,
For: Holidays,
Until: 06:00, 0,
Until: 14:00, 1,
Until: 16:00, 0,
Until: 19:00, 1,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

APPENDIX F

Construction data input in IES VE: Case study building model for validation.

Table F-1 Ground floor's fabric data

Ground floor’s fabric data					
Source		IES VE			
Category		Floor			
U-Value (W/m²K)		3.264			
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[CNCR0000] Concrete slab	100	1.795	2367.0	901.0	0.056
[CMNT0000] Cement screed	22	0.658	1650.0	840.0	0.033
[CYT1] Ceramic tile	8	1.107	2022.0	1250.0	0.007

Table F-2 wall's fabric data

Wall's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	2.8939				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table F-3 Internal partition's fabric data

Internal partition's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	2.2959				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table F-4 Glazed fabric data

Glazed fabric data

Source IES VE
 Category Window
 U-Value (W/m²K) 4.8293
 g-value 0.8199

Construction layers (outside to inside)

Material	Thickness (mm)	Conductivity W/(m·K)	Transmittance
[CF6] CLEAR FLOAT 6MM	6	1.060	0.780

Table F-5 Ceiling's fabric data

Ceiling's fabric data

Source IES VE
 Category Ceiling
 U-Value (W/m²K) 3.1250

Construction layers (outside to inside)

Material	Thickness (mm)	Conductivity W/(m·K)	Density Kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W
[STD_US41 Ceiling board 6mm	6	0.050	640.0	1150.0	0.120

Table F-6 Roof's fabric data

Roof's fabric data

Source IES VE
 Category Roof
 U-Value (W/m²K) 3.3775

Construction layers (outside to inside)

Material	Thickness (mm)	Conductivity W/(m·K)	Density Kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W
[CYT] Clay tile	25	0.840	1900.0	800.0	0.030
Cavity	20	-	-	-	-
[RF] Roofing felt	5	0.190	960.0	837.0	0.026

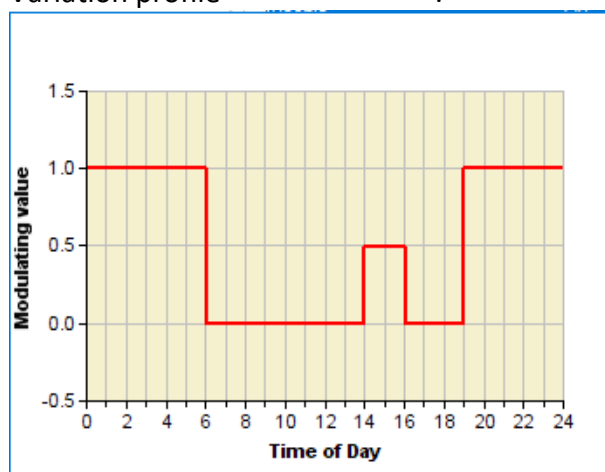
APPENDIX G

Schedule data input in IES VE: Case study building model for validation.

1. Occupancy schedule

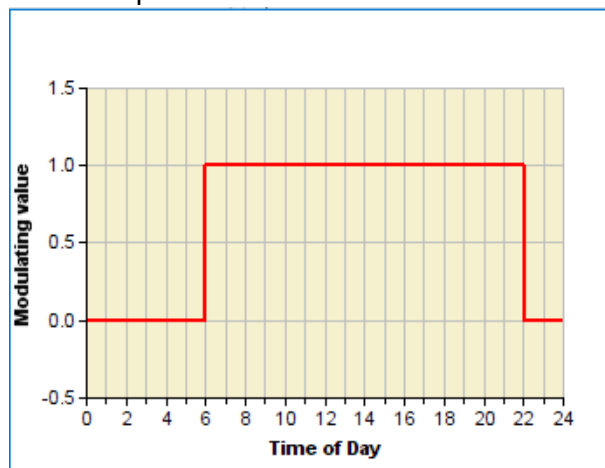
a. Master bedroom

Type : people 220-6 till 10-125
Maximum sensible gain (W/P) : 64.476
Maximum latent gain (W/P) : 29.307
Number of people : 3
Diversity factor : 1
Variation profile :



b. Living room

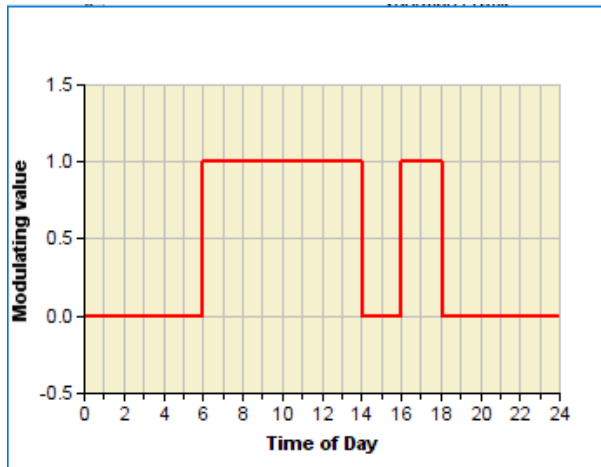
Type : people 220-6 till 10-125
Maximum sensible gain (W/P) : 64.476
Maximum latent gain (W/P) : 29.307
Number of people : 3
Diversity factor : 1
Variation profile :



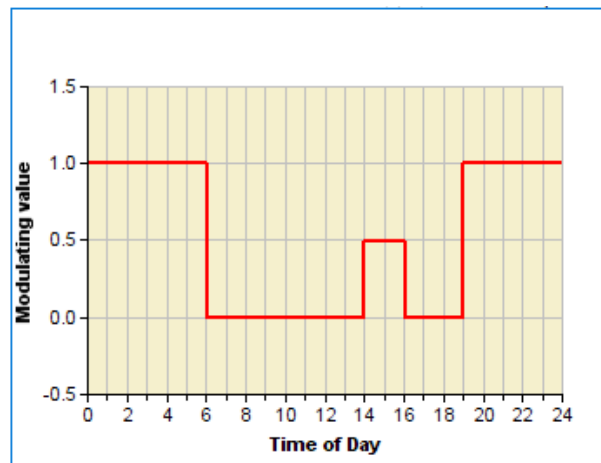
2. HVAC schedule

a. Master bedroom

Natural ventilation

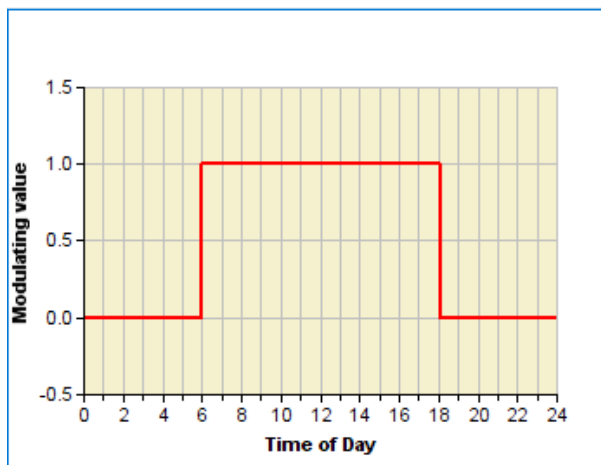


AC



b. Living room

Natural ventilation



APPENDIX H

Construction data input in DesignBuilder: Original building element model (OB model).

Table H-1 External wall's fabric data

External wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table H-2 Internal wall's fabric data

Internal wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table H-3 External party wall's fabric data

External party wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.244	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	200
Innermost layer (Layer 3)	Cement plaster	25

* Refer to DesignBuilder user manual (2019)

Table H-4 Calculated glazing data

Calculated glazing data _ 6mm single clear glass	
Total solar transmission (SHGC)	0.819
Direct solar transmission	0.775
Light transmission	0.881
U-value (ISO 10292/EN 673) (W/m ² -K)	5.718
U-value (W/m ² -K)	5.778

Table H-5 Ground floor's fabric data

Ground floor's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Floors (ground)	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.264	
		Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Concrete slab	100
Layer 2	Cement screed	22
Innermost layer (Layer 3)	Ceramic tile	8

* Refer to DesignBuilder user manual (2019)

Table H-6 Internal ceiling's fabric data

Internal ceiling's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Ceilings	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.125	
		Thickness (mm)
Number of layers	1	
Single layer	Ceiling board (6mm)	6

* Refer to DesignBuilder user manual (2019)

Table H-7 Pitched roof fabric data

Pitched roof fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Roofs	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	6.061	
		Thickness (mm)
Number of layers	1	
Single layer	Clay roof tile	25

* Refer to DesignBuilder user manual (2019)

APPENDIX I

Schedule data input in DesignBuilder: Original building element model (OB model).

1. Occupancy schedule

a. Master bedroom

Schedule:Compact,
Dwell_NO Occ Fify,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 24:00, 0,
For: Weekends,
Until: 24:00, 0,
For: Holidays,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

b. Living room

Schedule:Compact,
Dwell_NO Occ Fify,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 24:00, 0,
For: Weekends,
Until: 24:00, 0,
For: Holidays,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

2. HVAC schedule

a. Master bedroom

AC on 24/7

b. Living room

AC on 24/7

APPENDIX J

Construction data input in DesignBuilder: Passivhaus building model (PB model)

Table J-1 External wall's fabric data

External wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	0.627	Thickness (mm)
Number of layers	4	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Layer 3	EPS Expanded Polystyrene (Standard)	50
Innermost layer (Layer 4)	Cement plaster	25
* Refer to DesignBuilder user manual (2019)		

Table J-2 Internal wall's fabric data

Internal wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	2.894	Thickness (mm)
Number of layers	3	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	100
Innermost layer (Layer 3)	Cement plaster	25
* Refer to DesignBuilder user manual (2019)		

Table J-3 External party wall's fabric data

External party wall's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Walls	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	0.590	Thickness (mm)
Number of layers	4	
Outermost layer (Layer 1)	Cement plaster	25
Layer 2	Clay brick	200
Layer 3	EPS Expanded Polystyrene (Standard)	50
Innermost layer (Layer 4)	Cement plaster	25
* Refer to DesignBuilder user manual (2019)		

Table J-4 Calculated glazing data

Calculated glazing data _ Double low-e 6mm clear glass/13mm Air	
Total solar transmission (SHGC)	0.568
Direct solar transmission	0.474
Light transmission	0.745
U-value (ISO 10292/EN 673) (W/m ² -K)	1.679
U-value (W/m ² -K)	1.761

Table J-5 Ground floor's fabric data

Ground floor's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Floors (ground)	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	0.247	
		Thickness (mm)
Number of layers	4	
Outermost layer (Layer 1)	Urea Formaldehyde Foam	150
Layer 2	Concrete slab	100
Layer 3	Cement screed	22
Innermost layer (Layer 4)	Ceramic tile	8

* Refer to DesignBuilder user manual (2019)

Table J-6 Internal ceiling's fabric data

Internal ceiling's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Ceilings	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	3.125	
		Thickness (mm)
Number of layers	1	
Single layer	Ceiling board (6mm)	6

* Refer to DesignBuilder user manual (2019)

Table J-7 Pitched roof's fabric data

Pitched roof's fabric data		
Source	DesignBuilder (Energy Plus)	
Category	Roofs	
Definition method	Layers	
Simulation solution algorithm	Default*	
U-Value	0.193	
		Thickness (mm)
Number of layers	1	
Outermost layer (Layer 1)	Clay roof tile	25
Layer 2	MW Glass wool (rolls)	180
Innermost layer (Layer 3)	Roofing felt	5

* Refer to DesignBuilder user manual (2019)

APPENDIX K

Schedule data input in DesignBuilder: Passivhaus building model (PB model).

1. Occupancy schedule

a. Master bedroom

Schedule: Compact,
Dwell_NO Occ Fify,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 24:00, 0,
For: Weekends,
Until: 24:00, 0,
For: Holidays,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

b. Living room

Schedule: Compact,
Dwell_NO Occ Fify,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 24:00, 0,
For: Weekends,
Until: 24:00, 0,
For: Holidays,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;

2. HVAC schedule

a. Master bedroom

AC on 24/7

b. Living room

AC on 24/7

APPENDIX L

Construction data input in IES VE: Original building element model (OB model).

Table L-1 Ground floor's fabric data

Ground floor's fabric data					
Source		IES VE			
Category		Floor			
U-Value (W/m²K)		3.264			
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[CNCR0000] Concrete slab	100	1.795	2367.0	901.0	0.056
[CMNT0000] Cement screed	22	0.658	1650.0	840.0	0.033
[CYT1] Ceramic tile	8	1.107	2022.0	1250.0	0.007

Table L-2 wall's fabric data

Wall's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	2.8939				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table L-3 Internal partition's fabric data

Internal partition's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	2.2959				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table L-4 Glazed fabric data

Glazed fabric data

Source IES VE
 Category Window
 U-Value (W/m²K) 4.8293
 g-value 0.8199

Construction layers (outside to inside)

Material	Thickness (mm)	Conductivity W/(m·K)	Transmittance
[CF6] CLEAR FLOAT 6MM	6	1.060	0.780

Table L-5 Ceiling's fabric data

Ceiling's fabric data

Source IES VE
 Category Ceiling
 U-Value (W/m²K) 3.1250

Construction layers (outside to inside)

Material	Thickness (mm)	Conductivity W/(m·K)	Density Kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W
[STD_US41 Ceiling board 6mm	6	0.050	640.0	1150.0	0.120

Table L-6 Roof's fabric data

Roof's fabric data

Source IES VE
 Category Roof
 U-Value (W/m²K) 3.3775

Construction layers (outside to inside)

Material	Thickness (mm)	Conductivity W/(m·K)	Density Kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W
[CYT] Clay tile	25	0.840	1900.0	800.0	0.030
Cavity	20				
[RF] Roofing felt	5	0.190	960.0	837.0	0.026

APPENDIX M

Construction data input in IES VE: Passivhaus building model (PB model).

Table M-1 Insulated ground floor's fabric data

Insulated ground floor's fabric data					
Source	IES VE				
Category	Floor				
U-Value (W/m²K)	0.2322				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[STD_EPS] Insulation	100	0.025	20.0	1030.0	4.000
[CNCR0000] Concrete slab	100	1.795	2367.0	901.0	0.056
[CMNT0000] Cement screed	22	0.658	1650.0	840.0	0.033
[CYT1] Ceramic tile	8	1.107	2022.0	1250.0	0.007

Table M-2 Insulated wall's fabric data

Insulated wall's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	0.1576				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[STD_EPS] Insulation	150	0.025	20.0	1030.0	6.000
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table M-3 Internal partition's fabric data

Internal partition's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	2.2959				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table M-4 Double-Glazed Window's fabric data

Double-Glazed Window's fabric data			
Source	IES VE		
Category	Window		
U-Value (W/m²K)	3.1704		
g-value	0.7062		
Construction layers (outside to inside)			
Material	Thickness (mm)	Conductivity W/(m·K)	Transmittance
[CF6] CLEAR FLOAT 6MM	6	1.060	0.780
Cavity	12	-	-
[CF6] CLEAR FLOAT 6MM	6	1.060	0.780

Table M-5 Ceiling's fabric data

Table 10.5 Ceiling's fabric data					
Source		IES VE			
Category		Ceiling			
U-Value (W/m²K)		3.1250			
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[STD_US41 Ceiling board 6mm	6	0.050	640.0	1150.0	0.120

Table M-6 Insulated roof's fabric data

Insulated roof's fabric data					
Source	IES VE				
Category	Roof				
U-Value (W/m²K)	0.1205				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[CYT] Clay tile	25	0.840	1900.0	800.0	0.030
Cavity	20	-	-	-	-
[STD_EPS] Insulation	200	0.025	20.0	1030.0	8.000
[RF] Roofing felt	5	0.190	960.0	837.0	0.026

APPENDIX N

Construction data input in IES VE: Passivhaus building model without floor insulation (PB model without floor insulation).

Table N-1 Ground floor's fabric data

Ground floor's fabric data					
Source	IES VE				
Category	Floor				
U-Value (W/m²K)	3.264				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[CNCR0000] Concrete slab	100	1.795	2367.0	901.0	0.056
[CMNT0000] Cement screed	22	0.658	1650.0	840.0	0.033
[CYT1] Ceramic tile	8	1.107	2022.0	1250.0	0.007

Table N-2 Insulated wall's fabric data

Insulated wall's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	0.1576				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[STD_EPS] Insulation	150	0.025	20.0	1030.0	6.000
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table N-3 Internal partition's fabric data

Internal partition's fabric data					
Source	IES VE				
Category	Wall				
U-Value (W/m²K)	2.2959				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038
[BRO1] Clay brick	100	1.000	1827.0	852.0	0.100
[PLD1] Cement plaster	25	0.529	1300.0	890.0	0.038

Table N-4 Double-Glazed Window's fabric data

Double-Glazed Window's fabric data			
Source	IES VE		
Category	Window		
U-Value (W/m²K)	3.1704		
g-value	0.7062		
Construction layers (outside to inside)			
Material	Thickness (mm)	Conductivity W/(m·K)	Transmittance
[CF6] CLEAR FLOAT 6MM	6	1.060	0.780
Cavity	12	-	-
[CF6] CLEAR FLOAT 6MM	6	1.060	0.780

Table N-5 Ceiling's fabric data

Ceiling's fabric data					
Source	IES VE				
Category	Ceiling				
U-Value (W/m²K)	3.1250				
Construction layers (outside to inside)					
Material	Thickness (mm)	Conductivity W/(m·K)	Density Kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W
[STD_US41 Ceiling board 6mm	6	0.050	640.0	1150.0	0.120

Table N-6 Insulated roof's fabric data

Insulated roof's fabric data					
Source	IES VE				
Category	Roof				
U-Value (W/m²K)	0.1205				
Construction layers (outside to inside)					
Material	Thickness	Conductivity	Density	Specific Heat Capacity	Resistance
	(mm)	W/(m·K)	Kg/m³	J/(kg·K)	m²K/W
[CYT] Clay tile	25	0.840	1900.0	800.0	0.030
Cavity	20	-	-	-	-
[STD_EPS] Insulation	200	0.025	20.0	1030.0	8.000
[RF] Roofing felt	5	0.190	960.0	837.0	0.026

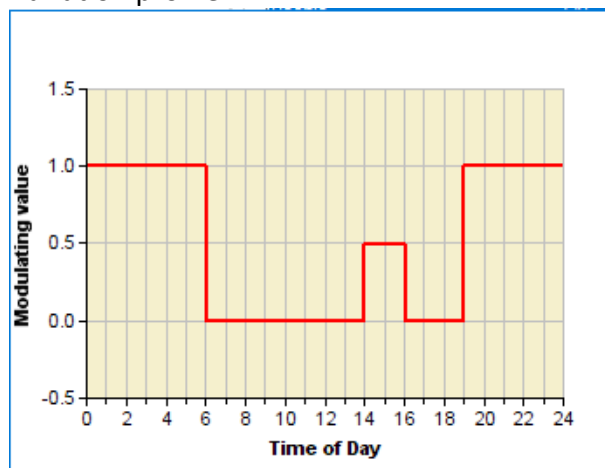
APPENDIX O

Schedule data input in IES VE: Original building element model (OB model), Passivhaus building model (PB model) and Passivhaus building model without floor insulation (PB model without floor insulation).

1. Occupancy schedule

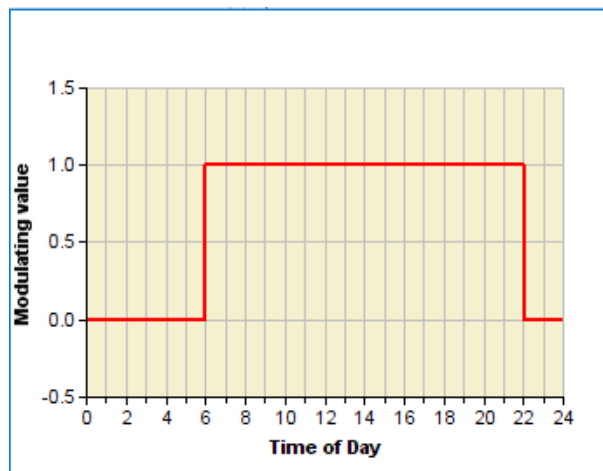
a. Master bedroom

Type : people 220-6 till 10-125
Maximum sensible gain (W/P) : 64.476
Maximum latent gain (W/P) : 29.307
Number of people : 3
Diversity factor : 1
Variation profile :



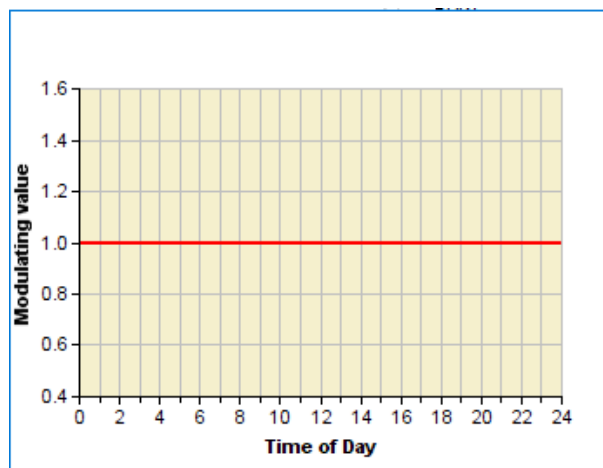
b. Living room

Type : people 220-6 till 10-125
Maximum sensible gain (W/P) : 64.476
Maximum latent gain (W/P) : 29.307
Number of people : 3
Diversity factor : 1
Variation profile :

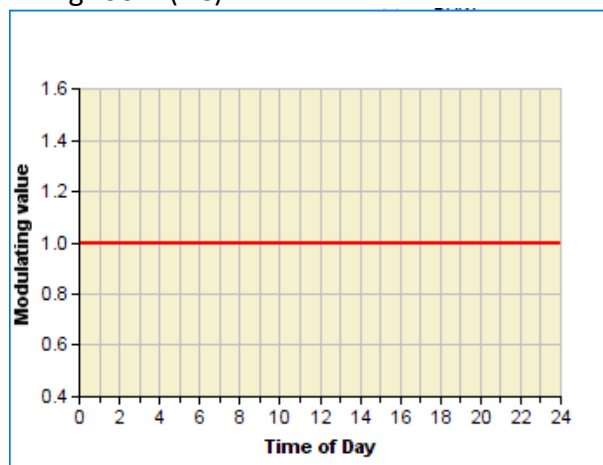


2. HVAC schedule

a. Master bedroom (AC)



b. Living room (AC)



APPENDIX P

PHPP settings.

Passive House Verification																																																																													
<div style="border: 1px dashed black; width: 100%; height: 100%; text-align: center; line-height: 100px;">Photo or Drawing</div>			<div style="display: flex; justify-content: space-between;"> <div> Building: Jakarta house (Passivhaus application) Street: <input type="text"/> Postcode/City: <input type="text"/> Province/Country: <input type="text" value="ID-Indonesia"/> Building type: <input type="text"/> Climate data set: ud-01-Jakarta climate 1 Climate zone: 7: Very hot Altitude of location: 80 m </div> <div> Home owner / Client: Street: <input type="text"/> Postcode/City: <input type="text"/> Province/Country: <input type="text" value="ID-Indonesia"/> </div> </div>																																																																										
Architecture: <input type="text"/> Street: <input type="text"/> Postcode/City: <input type="text"/> Province/Country: <input type="text" value="ID-Indonesia"/>			Mechanical system: Street: <input type="text"/> Postcode/City: <input type="text"/> Province/Country: <input type="text" value="ID-Indonesia"/>																																																																										
Energy consultancy: <input type="text"/> Street: <input type="text"/> Postcode/City: <input type="text"/> Province/Country: <input type="text" value="ID-Indonesia"/>			Certification: Street: <input type="text"/> Postcode/City: <input type="text"/> Province/Country: <input type="text" value="ID-Indonesia"/>																																																																										
Year of construction: <input type="text" value="2014"/> No. of dwelling units: <input type="text" value="1"/> No. of occupants: <input type="text" value="1.4"/>			<div style="display: flex; justify-content: space-between;"> <div> Interior temperature winter [°C]: <input type="text" value="20.0"/> Internal heat gains (IHG) heating case [W/m²]: <input type="text" value="3.1"/> Specific capacity [Wh/K per m² TFA]: <input type="text" value="60"/> </div> <div> Interior temp. summer [°C]: <input type="text" value="25.0"/> IHG cooling case [W/m²]: <input type="text" value="3.1"/> Mechanical cooling: <input type="text" value="x"/> </div> </div>																																																																										
Specific building characteristics with reference to the treated floor area																																																																													
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="2"></th> <th style="text-align: center;">Treated floor area m²</th> <th></th> <th style="text-align: center;">Criteria</th> <th style="text-align: center;">Alternative criteria</th> <th style="text-align: center;">Fulfilled?²</th> </tr> </thead> <tbody> <tr> <td rowspan="2" style="text-align: left;">Space heating</td> <td>Heating demand kWh/(m²a)</td> <td style="text-align: center;">48.0</td> <td>≤</td> <td style="text-align: center;">15</td> <td style="text-align: center;">-</td> <td rowspan="2" style="text-align: center; background-color: #d4edda;">yes</td> </tr> <tr> <td>Heating load W/m²</td> <td style="text-align: center;">-</td> <td>≤</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> </tr> <tr> <td rowspan="4" style="text-align: left;">Space cooling</td> <td>Cooling & dehum. demand kWh/(m²a)</td> <td style="text-align: center;">129</td> <td>≤</td> <td style="text-align: center;">46</td> <td style="text-align: center;">87</td> <td rowspan="4" style="text-align: center; background-color: #f8d7da;">no</td> </tr> <tr> <td>Cooling load W/m²</td> <td style="text-align: center;">16</td> <td>≤</td> <td style="text-align: center;">-</td> <td style="text-align: center;">11</td> </tr> <tr> <td>Frequency of overheating (> 25 °C) %</td> <td style="text-align: center;">-</td> <td>≤</td> <td style="text-align: center;">-</td> <td></td> </tr> <tr> <td>Frequency excessively high humidity (> 12 g/kg) %</td> <td style="text-align: center;">0</td> <td>≤</td> <td style="text-align: center;">10</td> <td></td> </tr> <tr> <td style="text-align: left;">Airtightness</td> <td>Pressurization test result n₅₀ 1/h</td> <td style="text-align: center;">0.4</td> <td>≤</td> <td style="text-align: center;">0.6</td> <td></td> <td style="text-align: center; background-color: #d4edda;">yes</td> </tr> <tr> <td style="text-align: left;">Non-renewable Primary Energy (PE)</td> <td>PE demand kWh/(m²a)</td> <td style="text-align: center;">247</td> <td>≤</td> <td style="text-align: center;">120</td> <td></td> <td style="text-align: center; background-color: #f8d7da;">no</td> </tr> <tr> <td style="text-align: left;">Primary Energy</td> <td>PER demand kWh/(m²a)</td> <td style="text-align: center;">135</td> <td>≤</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> <td rowspan="2" style="text-align: center; background-color: #d4edda;">-</td> </tr> <tr> <td style="text-align: left;">Renewable (PER)</td> <td>Generation of renewable energy kWh/(m²a)</td> <td style="text-align: center;">0</td> <td>≥</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> </tr> </tbody> </table>												Treated floor area m²		Criteria	Alternative criteria	Fulfilled? ²	Space heating	Heating demand kWh/(m²a)	48.0	≤	15	-	yes	Heating load W/m²	-	≤	-	-	Space cooling	Cooling & dehum. demand kWh/(m²a)	129	≤	46	87	no	Cooling load W/m²	16	≤	-	11	Frequency of overheating (> 25 °C) %	-	≤	-		Frequency excessively high humidity (> 12 g/kg) %	0	≤	10		Airtightness	Pressurization test result n ₅₀ 1/h	0.4	≤	0.6		yes	Non-renewable Primary Energy (PE)	PE demand kWh/(m²a)	247	≤	120		no	Primary Energy	PER demand kWh/(m²a)	135	≤	-	-	-	Renewable (PER)	Generation of renewable energy kWh/(m²a)	0	≥	-	-
		Treated floor area m²		Criteria	Alternative criteria	Fulfilled? ²																																																																							
Space heating	Heating demand kWh/(m²a)	48.0	≤	15	-	yes																																																																							
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Non-renewable Primary Energy (PE)	PE demand kWh/(m²a)	247	≤	120		no																																																																							
Primary Energy	PER demand kWh/(m²a)	135	≤	-	-	-																																																																							
Renewable (PER)	Generation of renewable energy kWh/(m²a)	0	≥	-	-																																																																								
² Empty field: Data missing; '-': No requirement																																																																													
I confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The PHPP calculations are attached to this verification.						Passive House Classic? <input type="text" value="no"/>																																																																							
Task: <input type="text"/>		First name: <input type="text"/>		Surname: <input type="text"/>		Signature: _____																																																																							
Issued on: <input type="text"/>				City: <input type="text"/>																																																																									





Passive House with PHPP Version 9.3

Jakarta house (Passivhaus application) / Climate: Jakarta climate 1 / TFA: 48 m² / Cooling: 167.9 kWh/(m²a) / PER: 161.2 kWh/(m²a)

Secondary calculation: Equivalent thermal conductivity of still air spaces -> (on the right)

Wedge-shaped assembly layer -> (on the right)

Unheated / uncooled attic -> (on the right)

Assembly no.	Building assembly description					Interior insulation?
01tud	External wall					
		Heat transmission resistance [m ² K/W]				
Orientation of building element		2-Wall	interior R _{si}	0.13		
Adjacent to		1-Outdoor air	exterior R _{se}	0.04		
Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness (mm)
Interior plaster	0.529					25
Clay Brick	1.000					100
Kingspan	0.022					200
Exterior plaster	0.529					25
Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3		Total
100%						35.0 cm
U-value supplement				U-value: 0.106		W/(m ² K)

Assembly no.						Interior insulation?
O2ud	Roo					
		Heat transmission resistance [m²K/W]				
Orientation of building element		interior R _{s,i}	0.17			
Adjacent to		exterior R _{s,e}	0.04			
Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Clay tile	1.000					25
Glass wall roof	0.040					200
Roofing felt	0.190					5
Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3		Total
100%						23.0 cm
U-value supplement		W/(m²K)		U-value:		0.190 W/(m²K)

Assembly no.							Interior insulation?
03ud	Floor						
Heat transmission resistance [m ² K/W]							
Orientation of building element		3-Floor	interior R _{si}		0.10		
Adjacent to		2-Ground	exterior R _{se}		0.00		
Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]	
Ceramic tile	1.108					8	
Cement screed	0.658					22	
Concrete slab	1.795					100	
Kingspan	0.022					200	
Percentage of sec. 1 100%		Percentage of sec. 2		Percentage of sec. 3		Total 33.0 cm	
U-value supplement		W/(m ² K)		U-value:		0.108 W/(m ² K)	

Assembly no.		Interior insulation?	
O4ud	Partition wall		
		Heat transmission resistance [m ² K/W]	
Orientation of building element:	2-Wall	interior R _{si} :	0.13
	Adjacent to: 3-Ventilated	exterior R _{se} :	0.13
Area section 1		λ [W/(mK)]	Area section 2 (optional)
Interior plaster	0.529		
Clay Brick	1.000		
Exterior plaster	0.529		
Percentage of sec. 1		Percentage of sec. 2	Percentage of sec. 3
100%			
U-value supplement	U [W/(m ² K)]	Total U-value: 2.200 W/(m ² K)	

Windows

Jakarta house (Passivhaus application) / Climate: Jakarta climate 1 / TFA: 48 m² / Cooling: 167.9 kWh/(m²a) / PER: 161.2 kWh/(m²a)

Window area orientation	Global radiation (main orientations)	Shading	Dirt	Non-vertical radiation incidence	Glazing fraction	g-Value	Solar irradiation reduction factor	Window area	Window U-Value	Glazing area	Average global radiation
Standard values →		0.75	0.95	0.85							
North	0	0.53	0.95	0.85	0.42	0.64	0.18	3.06	1.07	1.27	0
East	0	1.00	0.95	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0
South	0	0.25	0.95	0.85	0.41	0.55	0.08	2.16	0.90	0.88	0
West	0	1.00	0.95	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0
Horizontal	0	1.00	0.95	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0
Total or average value for all windows.											
						0.60	0.14	5.22	1.00	2.15	

[Go to glazing list](#)

[Go to window frames list](#)

Heating degree hours [kKh] 0.1

Quantity	Description	Deviation from north	Angle of inclination from the horizontal	Window rough openings		Installed in	Glazing	Frame	g-Value	U-Value		ψ _{glazing edge} (Avg.)
				Width	Height					Glazing	Frames (avg.)	
1	North living window	0	90	0.600	1.500	2-External wall north	1-Sorting: LIKE LIST 99ud-Double low-E glazing 4/16Agon90% ϵ 4 Epsilon=0.1	1-Sorting: LIKE LIST 01ud-Standard PU on wood	-	W/(m²K) 1.30	W/(m²K) 0.59	W/(mK) 0.049
1	North Bedroom 1 window	0	90	0.600	1.200	2-External wall north	99ud-Double low-E glazing 4/16Agon90% ϵ 4 Epsilon=0.1	01ud-Standard PU on wood	Perpendicular radiation	1.30	0.59	0.049
1	North Bedroom 1 window	0	90	0.600	1.200	2-External wall north	99ud-Double low-E glazing 4/16Agon90% ϵ 4 Epsilon=0.1	01ud-Standard PU on wood	Perpendicular radiation	1.30	0.59	0.049
1	North Bedroom 1 window	0	90	0.600	1.200	2-External wall north	99ud-Double low-E glazing 4/16Agon90% ϵ 4 Epsilon=0.1	01ud-Standard PU on wood	Perpendicular radiation	1.30	0.59	0.049
1	South bedroom 2 window	180	90	0.600	1.200	1-External wall south	99ud-Double low-E glazing 4/16Agon90% ϵ 4 Epsilon=0.1	01ud-Standard PU on wood	Perpendicular radiation	1.30	0.59	0.049
1	South bedroom 2 window	180	90	0.600	1.200	1-External wall south	01ud-Triple-low-e K08	01ud-Standard PU on wood	Perpendicular radiation	0.70	0.59	0.049
1	South bedroom 2 window	180	90	0.600	1.200	1-External wall south	01ud-Triple-low-e K08	01ud-Standard PU on wood	Perpendicular radiation	0.70	0.59	0.049

Ventilation data

Passive House with PHPP Version 9.3

Jakarta house (Passivhaus application) / Climate: Jakarta climate 1 / TFA: 48 m² / Cooling: 167.9 kWh/(m²a) / PER: 161.2 kWh/(m²a)

Treated floor area A_{TFA}	m²	48	(Areas' worksheet)
Room height h	m	2.50	2.50
Volume of ventilated space ($A_{TFA} \cdot h$) V_V	m³	120	(Worksheet 'Annual heating')

Ventilation type

Please select

1-Balanced PH ventilation with HR

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for wind protection class	Several side exposed	One side exposed
No protection	0.10	0.03
Moderate protection	0.07	0.02
High protection	0.04	0.01
Coefficient f	15	20

Wind protection coefficient, e

For annual demand: 0.10 For heating load: 0.25

Wind protection coefficient, f

15 15

Net air volume for press. test V_{n50}

Air change rate at press. test n_{50}

1/h 0.40 0.40 480 m³

Air permeability q_{50} 1.29 m³/(h·m²)

For annual demand: For heating load:

Excess extract air

1/h 0.00 0.00

Infiltration air change rate $n_{V,Rest}$

1/h 0.160 0.400

Selection of ventilation input - Results

PHPP offers two methods for dimensioning air quantities and choosing the ventilation unit. With "Standard data input for balanced ventilation", supply or extract air quantities for residential buildings and parameters for ventilation systems with a maximum of 1 ventilation unit can be planned. Projects with up to 10 different ventilation units and air quantities determined according to rooms or zones can be entered in the 'Addl vent' worksheet. Please select your design method here:

Ventilation unit / Heat recovery efficiency design		Average air flow rate	Average air change rate	Extract air excess [extract air system]	Effective heat recovery efficiency unit	Energy recovery	Specific power input	Heat recovery efficiency SHX
		m³/h	1/h	1/h	[-]	[-]	Wh/m³	[-]
<input checked="" type="checkbox"/>	Standard design ('Ventilation' worksheet, see below)	92	0.77	0.00	73.5%	N/A	0.45	0.0%
<input type="checkbox"/>	Multiple ventilation units, non-res ('Addl vent' worksheet)							
					Cooling degree	Efficiency SHX		
					63.5%	η_{SHX} 0%		

Average interior humidity during winter operation

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-	-	-	-	-	-	-	-	-	-	-	-

Cooling: energy value for useful cooling energy

Passive House with PHPP Version 9.3

Jakarta house (Passivhaus application) / Climate: Jakarta climate 1 / TFA: 48 m² / Cooling: 167.9 kWh/(m²a) / PER: 161.2 kWh/(m²a)

The sum of the cooling periods calculated through the monthly method will be presented on this side.

Building type:			Treated floor area A _{TFA} :	48.0	m²
Interior temperature summer:	25	°C	Building volume:	120	m³
Nominal humidity:	12	g/kg	Internal humidity sources:	3.0	g/(m³h)
Spec. capacity:	60	Wh/(m³K)			

Building assembly	Temperature zone	Area m²	U-Value W/(m²K)	Mon. red. fac.	G _i kWh/a	kWh/a	per m² treated floor area
External wall - Ambient	A	33.2	0.106	1.00	-2	-7	-0.15
External wall - Ground	B			1.00			
Roof/Ceiling - Ambient	A	62.4	0.190	1.00	-2	-24	-0.49
Floor slab / Basement ceiling	B	48.0	0.108	1.00	-21	-110	-2.30
	A			1.00			
	A			1.00			
	X			0.75			
Windows	A	5.2	0.996	1.00	-2	-10	-0.22
Exterior door	A			1.00			
Exterior TB (length/m)	A			1.00			0.00
Perimeter TB (length/m)	P			1.00			0.00
Ground TB (length/m)	B			1.00			0.00
							kWh/(m²a)

Transmission losses Q_T (negative: heat loads)

Total -151 -3.2

Summer ventilation from 'Summ/ent' worksheet

Ventilation conductance, vent. unit

exterior H _{V,a}	11.1	W/K
without HR	30.5	W/K
ground H _{V,g}	0.0	W/K
without HR	0.0	W/K

Ventilation conductance, others

exterior	6.3	W/K
----------	-----	-----

Ventilation parameter

Temperature amplitude summer	7.3	K
Minimum acceptable indoor temperature	22.0	°C
Heat capacity air	0.33	Wh/(m³K)
Supply air changes	0.77	1/h
Outdoor air changes	0.16	1/h
Window night vent. air change rate, manual @ 1K	0.00	1/h
Air changes rate due to mech., autom. controlled vent.	0.00	1/h
Specific power consumption for	0.00	Wh/m³
η _{HR}	64%	
η _{ERV}	0%	
η*SHX	0%	

Summer ventilation regulation

HRV/ERV in summer	
Controlled by temp.	
Controlled by enthalpy	x
Always	
Additional ventilation	
Controlled by temp.	
Controlled by humidity	x

Hygienic air change

Effective air change rate Ambient n _{V,a}	0.769
Effective air change rate Ground n _{V,g}	0.769

n _{V,system} 1/h	η*SHX	η _{HR} (considers bypass)	n _{V,Rest} 1/h	n _{V,equi.fraction} 1/h
0.769	0%	0.64	0.160	0.441
0.769	0%	0.64		0.000

Ventilation losses ambient Q_V

Ventilation losses ground Q_{V,g}

Heat losses summer ventilation

V _V m³	n _{V,equi.fraction} 1/h	C _{Air} Wh/(m³K)	G _i kWh/a	kWh/a	kWh/(m²a)
120	0.441	0.33	-12	-201	-4.2
120	0.000	0.33	0	0	0.0
120	0.000	0.33	0	0	0.0

Ventilation heat losses Q_V

Total -201 -4.2

Total heat losses Q_L

Q _T kWh/a	Q _V kWh/a	kWh/a	kWh/(m²a)
-151	-201	-353	-7.4

Orientation of the area	Reduction factor	g-Value (perp. radiation)	Area m²	Global radiation kWh/(m²a)	kWh/a	kWh/(m²a)
North	0.10	0.64	3.1	858	166	
East	0.40	0.00	0.0	970	0	
South	0.08	0.55	2.2	669	62	
West	0.40	0.00	0.0	951	0	
Horizontal	0.40	0.00	0.0	1742	0	
Sum opaque areas					804	

Available solar heat gains Q_S

Total 1032 21.5

Internal heat gains Q _I	h/d	Length heat. period d/a	Spec. power q _i W/m²	A _{TFA} m²	kWh/a	kWh/(m²a)
0.024		365	3.1	48.0	1321	27.5

Sum heat loads Q_F

Q_S + Q_I = 2353 49.0

Ratio of losses to free heat gains Q_L / Q_F = -0.15

Utilisation factor heat losses η_G = 100%

Useful heat losses Q_{V,n}

η_G * Q_L = -353 -7.4

Useful cooling demand Q_K

Q_F - Q_{V,n} = 2706 56

Recommended maximum value

kWh/(m²a) 55

Requirement met? No

Compressor - cooling units

Passive House with PHPP Version 9.3

Jakarta house (Passivhaus application) / Climate: Jakarta climate 1 / TFA: 48 m² / Cooling: 167.9 kWh/(m²a) / PER: 161.2 kWh/(m²a)

Building type:			Treated floor area A _{TFA} :	48.0	m²
Interior temperature summer:	25.0	°C	Mechanical cooling:	x	
Nominal humidity:	12.0	g/kg	Air change rate via ventilation system with supply air:	0.8	
Internal humidity sources:	3.0	g/(m²h)			

☒ Supply air cooling

check as appropriate

On/Off mode (check as appropriate)

Max. cooling capacity (sensible + latent)

Temperature reduction dry

Seasonal energy efficiency ratio

x
2.0
63.7
2.0

kW
K

☐ Recirculation cooling

check as appropriate

On/Off mode (check as appropriate)

Max. cooling capacity (sensible + latent)

Volume flow rate at nominal power

Temperature reduction dry

Variable air volume (check if appropriate)

Seasonal energy efficiency ratio

x
2.0
600.0
9.8
x
3.2

kW
m³/h
K

☒ Additional dehumidification

check as appropriate

Waste heat to room (please check if applicable)

Seasonal energy efficiency ratio

2.0

☐ Panel cooling

check as appropriate

Seasonal energy efficiency ratio

0.1

	Sensible kWh/(m²a)	Latent kWh/(m²a)	COP	Electricity demand (kWh/a)	Sensible fraction
Useful cooling total	56.4	111.5			34%
Cooling contribution by:					
Supply air cooling	(56.4	+ 13.2) / 2.0	= 34.8	81%
Recirculation cooling	(+ 98.3) / 3.2	=	
Dehumidification			/ 2.0	= 49.2	0%
Remaining for panel cooling			/ 0.1	=	100%
Cooling distribution			/ 2.0	=	100%
Total	(56.4	+ 111.5) / 2.0	= 84.0	34%

Unsatisfied demand	0.0	0.0	Cooling demand covered?	(Yes/No)
				Yes

APPENDIX Q

List of publications

1. Applying the Passivhaus standard to a terraced house in a hot and humid tropical climate – Evaluation of comfort and energy performance. Journal article in Building Services Engineering Research and Technology 2020, Vol. 41(3) 247–260 DOI: 10.1177/0143624420912511.
2. Modelling the impact of ground temperature and ground insulation on cooling energy use in a tropical house constructed to the Passivhaus standard. Conference paper that presented at International Sustainable Built Environment (SBE) 2019 – Cardiff, Wales, UK, September 2019.
3. Assessing internal conditions in typical housing built to Passivhaus Standard in Jakarta, Indonesia - analysis for a hot humid, tropical season. Conference paper that presented at 'CIBSE Technical Symposium 2019: Transforming Built Environments - driving change with engineering' – Sheffield, UK, April 2019.
4. Evaluating the effect on thermal comfort and energy use of applying the Passivhaus standard to a dwelling in a hot humid climate – a case study in Jakarta, Indonesia. Conference paper that presented at 'Comfort at the Extremes (CATE 2019): Energy, Economy and Climate' – Dubai, UEA, April 2019.
5. Assessing Cooling Energy Load and Dehumidification in Housing Built to Passivhaus Standard in Jakarta, Indonesia. Conference paper that presented at '33rd PLEA International Conference: Design to Thrive' – Edinburgh, UK, July 2017.

